Volume 32 AUGUST, 1948 Number 8

BULLETIN
of the
American Association *of* Petroleum Geologists

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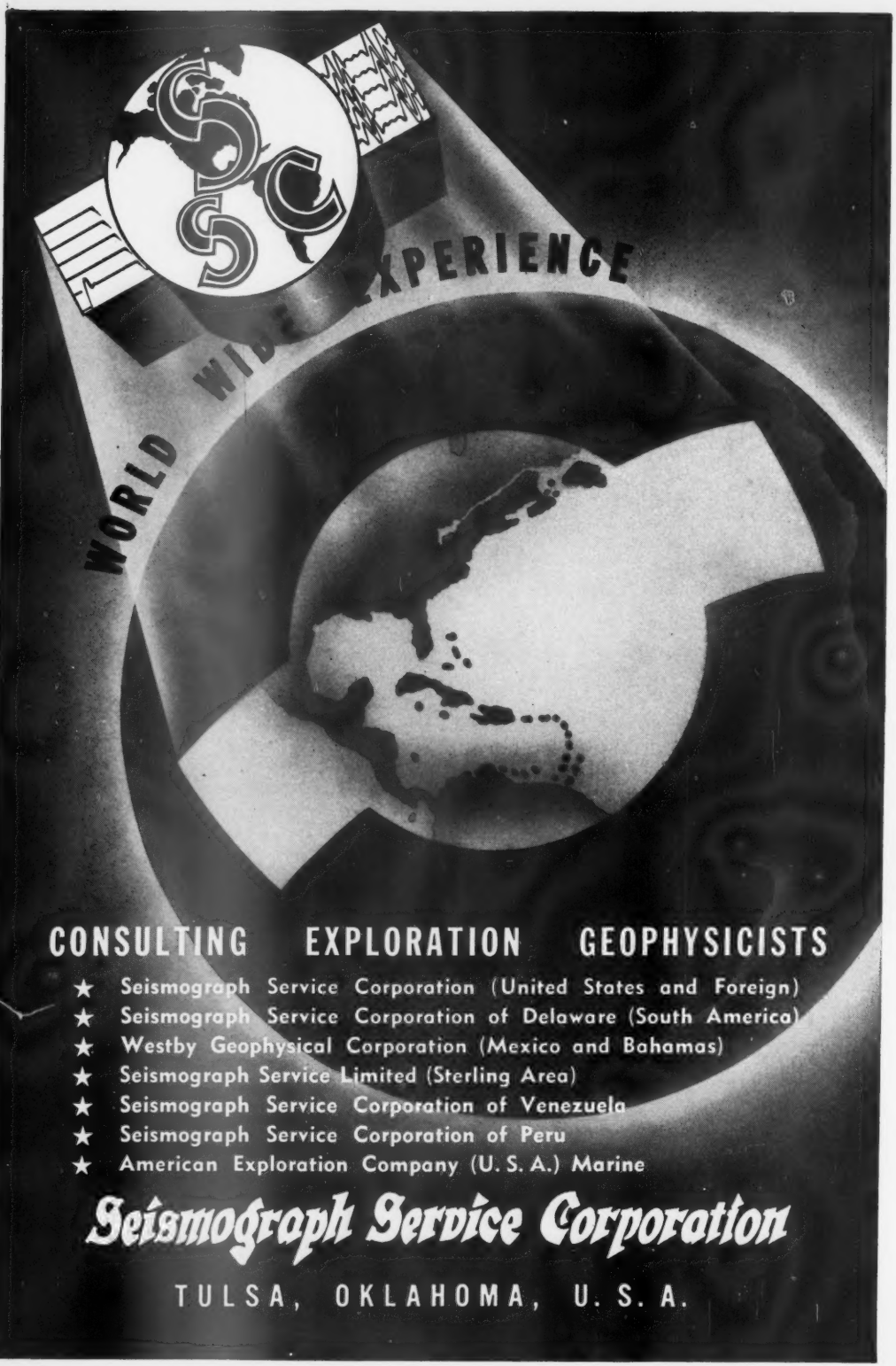
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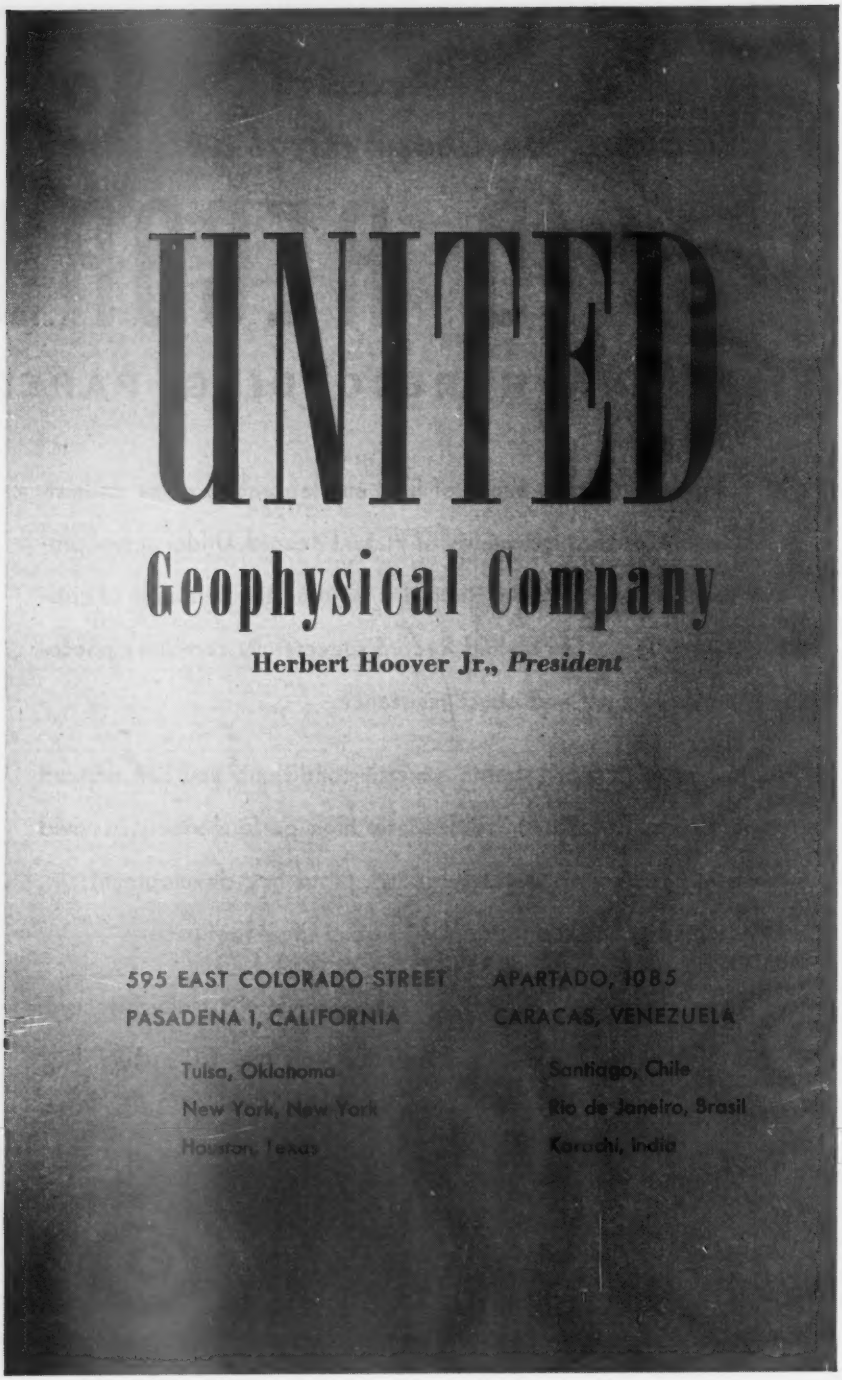
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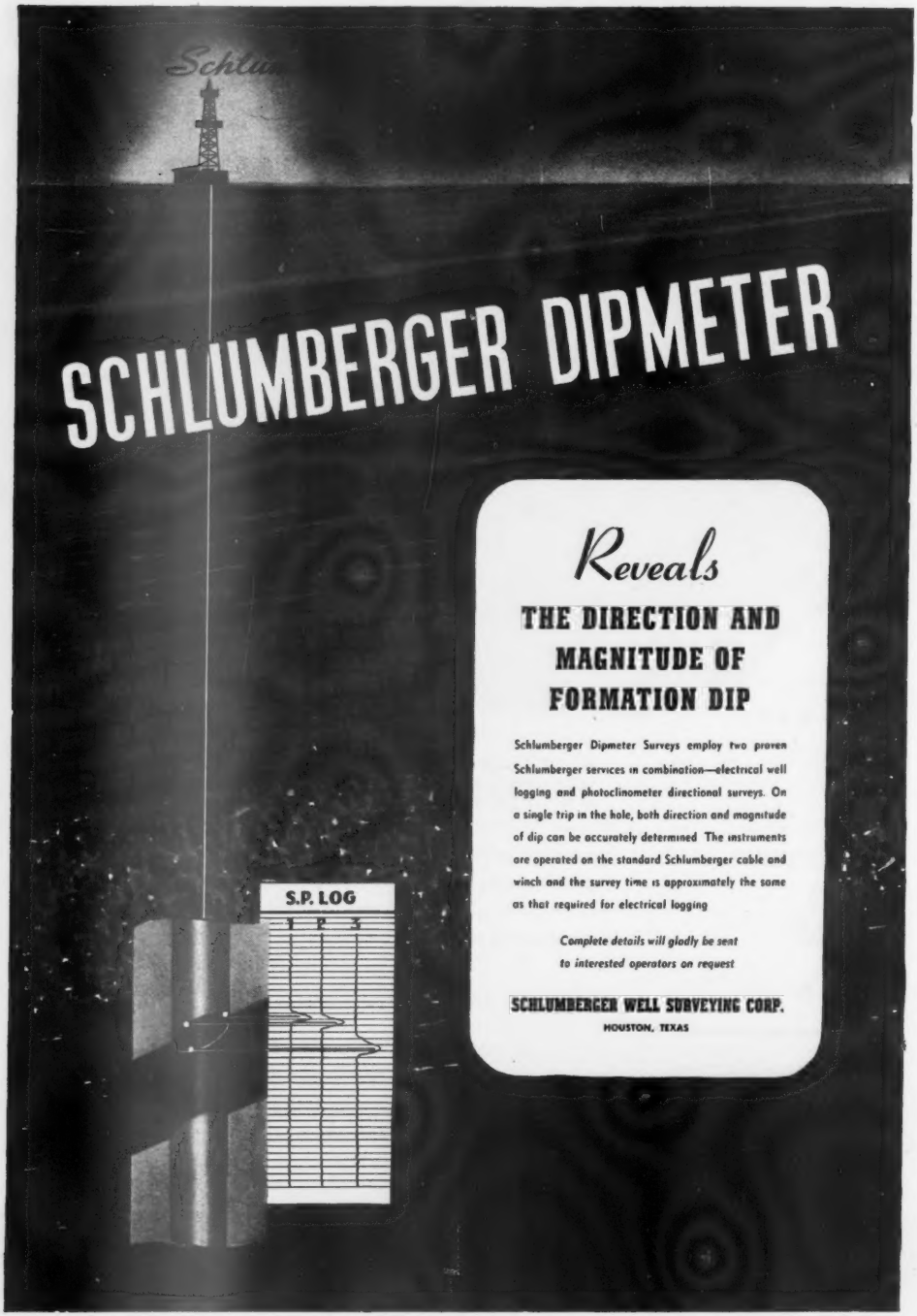
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By Ralph W. Imlay, Edmundo Cepeda, Manuel Alvarez and Teodor Diaz

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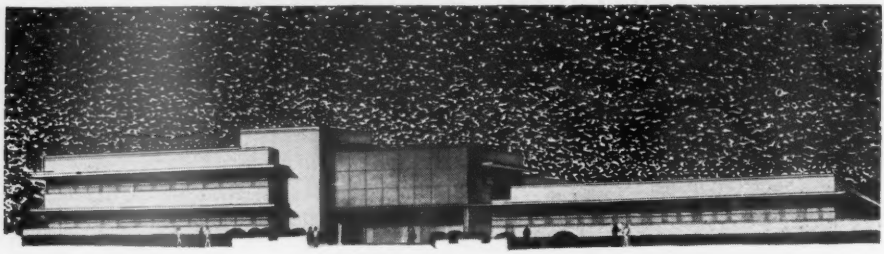

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Volume 32 Number 8

BULLETIN
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PETROLEUM GEOLOGISTS

AUGUST, 1948

APPALACHIAN BASIN ORDOVICIAN SYMPOSIUM
FOREWORD

JOHN T. GALEY[1]
Pittsburgh, Pennsylvania

Petroleum and natural gas were discovered in Ordovician rocks of the Appalachian Province 2½ decades after the bringing-in of the Drake well. This discovery was followed by intensive development of the Lima-Indiana field in northwestern Ohio and east-central Indiana, where oil is still being produced from the Trenton. To the present time, exploration of these rocks in the Appalachian region has been confined mainly to the shallower parts of the basin, and outside the area mentioned. As is shown in Figure 1, oil has been produced in north-central New York, the Ontario Peninsula, southeastern Michigan, central Ohio, south-central Kentucky, northeastern Tennessee, and southwestern Virginia.

The attention of geologists has recently been directed to the practicability of exploring the untested possibilities of Ordovician and lower rocks in the deeper part of the Appalachian basin by the following factors: the desperate need for new reserves; the widespread occurrence of oil and gas in these rocks in the shallower parts of the basin; the production of Pennsylvania-grade oil in southwestern Virginia; the interesting showings encountered in the few widely scattered wildcat wells in the deeper parts of the basin; the importance of the production of oil and gas from the Ellenburger group of Texas and from the Arbuckle group of Oklahoma and Kansas, which corresponds with the Knox group (sub-Trenton) of the Appalachian area, in mass, lithologic character and in stratigraphic position; and the demonstration of the ability to drill these rocks to the world's record cable-tool depth of 10,096 feet in relatively short time and at comparatively low cost.

[1] Chairman, editorial committee, Pittsburgh Geological Society. Other committee members: J. F. Pepper, C. E. Prouty, R. E. Sherrill, R. E. Somers. The papers in this symposium were given before the Pittsburgh Geological Society on May 16, 1947.

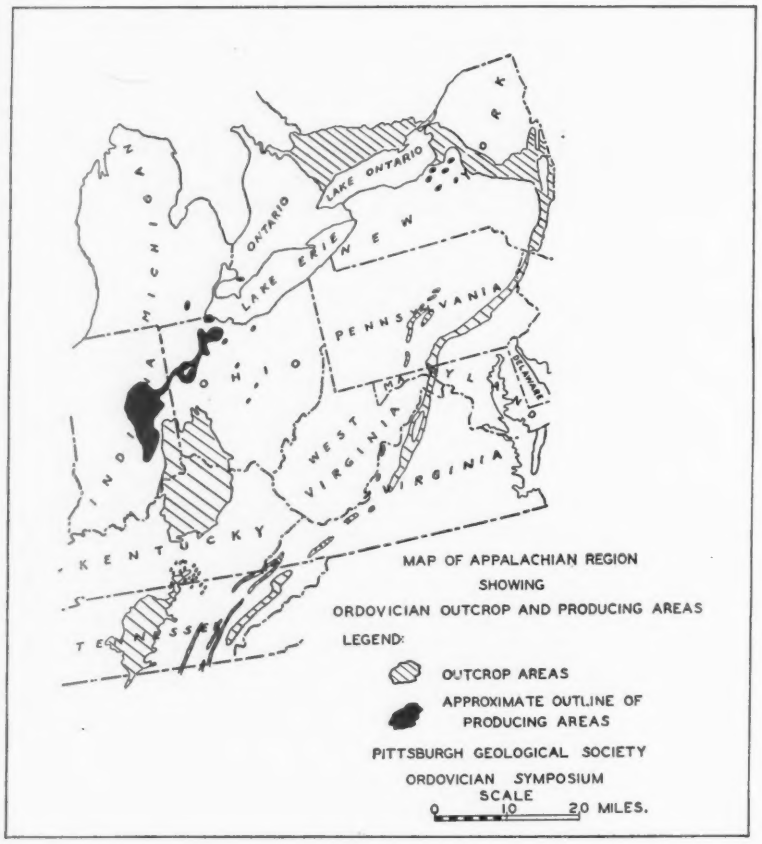

FIG. 1

This symposium is an attempt to bring together all available information about structure, stratigraphy, and paleontology, as well as oil and gas possibilities, which bear on the Ordovician rocks of the Appalachian basin, with particular emphasis on the Trenton and sub-Trenton. It is considered by no means the solution of the problems involved in prospecting in these rocks; it is intended rather as a stimulus to further thought on problems, the solution of which will aid in the discovery of new oil and gas fields in the older rocks of the Appalachian basin.

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VOL. 32, NO. 8 (AUGUST, 1948), PP. 1397-1416, 6 FIGS.

SUMMARY OF MIDDLE ORDOVICIAN BORDERING ALLEGHENY SYNCLINORIUM[1]

MARSHALL KAY[2]
New York, New York

ABSTRACT

The Middle Ordovician is divided into the Chazyan, Bolarian, and Trentonian series. The lower Chazyan Blackford and Five Oaks formations and equivalents probably underlie much of the synclinorium; the higher, Lincolnshire, seems limited to the southeastern border. The lower Bolarian Hatterian subseries is also extensive, thins northward by overlap and convergence; the succeeding Hunterian contrasts in thickening northwestward by divergence and addition of younger beds beneath a regional unconformity. The lower Trentonian has belts of differing facies in the south, and thins southeastward along the southeastern margin of the synclinorium. The middle Trentonian is limestone beneath and along the eastern margin, and becomes principally argillite farther southeast. The upper Trentonian stratigraphy has been studied only in the northeast.

INTRODUCTION

The subsurface of western Pennsylvania and West Virginia lies within the Allegheny synclinorium,[3] a broad, northeast-trending structural depression between the Cincinnati arch and the Appalachian structural front,[4] at the margin of the more deeply folded Appalachian Mountains (Fig. 1). The northern margin extends to the faulted pre-Cambrian highlands of central Ontario and the Frontenac arch, having the Ottawa-Bonnechere graben[5] and the Ottawa-St. Lawrence basin on the northeast.[6] The Adirondack block mountains are northeast of the synclinorium. Lower Paleozoic sediments crop out continuously along the borders of these limiting structures.

In Pennsylvania and southwestward, a series of narrow anticlines exposes Ordovician rocks interruptedly east of the structural front, the interval of concealment from the northern Nippenose anticline near Lockhaven to the outcrops along West Canada Creek near Utica, New York (Fig. 3), being approximately 200 miles, about twice that from the southern end of the southern Pennsylvania anticline east of Bedford to the northern end of the anticline west of Franklin, West Virginia. The sequences in anticlines along the structural front are isolated by a synclinorium more than 30 miles wide from the quite different sections in the Appalachian Valley for a distance of nearly 250 miles from the series of anticlinal outcrops northwest of Chambersburg, Pennsylvania, to those in the vicinity of Covington, Virginia; the Broad Top syncline is at the northeast in

[1] Manuscript received, February 28, 1948.

[2] Professor of geology, Columbia University.

[3] Marshall Kay, "Development of the Northern Allegheny Synclinorium and Adjoining Regions," *Bull. Geol. Soc. America*, Vol. 53 (1942), pp. 1601–58.

[4] P. H. Price, "The Appalachian Structural Front," *Jour. Geol.*, Vol. 39 (1931), pp. 24–44.

[5] Marshall Kay, "Ottawa-Bonnechere Graben and Lake Ontario Homocline," *Bull. Geol. Soc. America*, Vol. 53 (1942), pp. 585–646.

[6] A. E. Wilson, "Geology of the Ottawa-St. Lawrence Lowland, Ontario and Quebec," *Geol. Survey Canada Mem. 241* (1946). 65 pp.

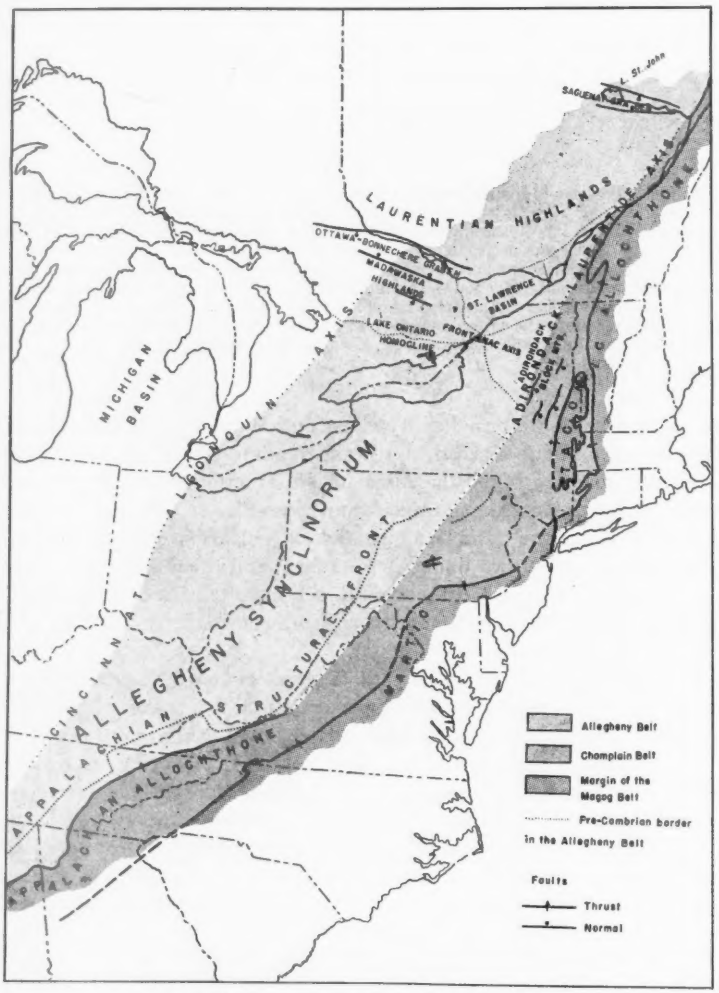


FIG. 1.—Allegheny synclinorium and adjoining regions. From *Bull. Geol. Soc. America* (1942).

Pennsylvania. Outcrops are fairly continuous in anticlines and thrust slices from southern West Virginia to Tennessee.[7]

The Allegheny synclinorium converges southwestward to extreme western Virginia and to the center of the Jessamine dome south of Lexington, Kentucky,

[7] C. E. Prouty, "Lower Middle Ordovician of Southwest Virginia and Northeast Tennessee," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 30 (1946), pp. 1140–91.

at which places the Ordovician outcrops are 100 miles apart. Exposures are lacking along the axis of the Cincinnati arch to the southern end of Georgian Bay, Lake Huron, more than 500 miles northeast; but many wells at intervals along the axis have been drilled through the Ordovician.

Thus, knowledge of the subsurface of the Allegheny synclinorium must be based on outcrops in Ontario and New York and wells for a hundred miles down the dip, on outcrops in anticlines beyond the Appalachian structural front, in the many belts in anticlines and thrust slices in Virginia, and in the central Kentucky Jessamine dome, and on the few wells along the Cincinnati arch on the northeast.

Stratigraphic provinces.—Cambrian and Lower Ordovician persist beneath the entire region excepting along the extreme northeast. The writer is most familiar with the Middle Ordovician north and east of the synclinorium, and he bases his discussion principally on these areas. Few of the units will be found thickest in the deepest part of the present structure, and some have maxima southeast of the region. The area of the synclinorium had differential warping in changing patterns through the Ordovician.

The Appalachian structural front does not have known correlation with Middle Ordovician strata. It is more convenient to refer to the Adirondack line, which conforms with striking stratigraphic changes of some geologic ages, though it has no evident relation to the strata of others. The line extends from Quebec City through the Adirondack Mountains to Canajoharie on the Mohawk, thence under the northeastern Allegheny synclinorium to Path Valley, west of Chambersburg, Pennsylvania, beneath the synclinorium east of the structural front to the terminus of the Saltville thrust near Newcastle, Virginia (Figs. 1 and 3). The geographic belts on the southeast and northwest are the Champlain and Allegheny belts, respectively; present discussion concerns the latter.

Lithologic characters and their nomenclature.—Carbonate rocks of many types are dominant in the Middle Ordovician of the Allegheny belt. To discuss them as limestones is not sufficiently descriptive of their lithic contrasts. Stratigraphers have come to apply in varying degrees the classification having compositional prefixes and textural suffixes. Thus, calcite rocks (calcitites) include several formations of clay texture (calcilutites), some of great economic importance as sources of chemical limestone. Other units have varying prevalence of sandstones of detrital calcite (calcarenites); calcitites composed of shells (coquinas) are relatively rare, and there are few units having organic reefs (bioherms). Many formations are of fine-textured argillaceous calcitite (argillicalcilutites) and calcareous argillites (calcargillutites). Argillites and quartz-sandy and silty argillites are more prevalent in the Champlain belt southeast of the Adirondack line, where hundreds of feet in southeastern sections approach source lands in some stages. Quartz sandstones and siltstones (silicarenites and silicisiltites) are uncommon, but some units have chert lenses and nodules that seem to have replaced carbonates soon after deposition, and a few carbonate units have considerable proportions of quartz sand and silt. Dolomite rocks (dolomitites) are practically limited

to the basal units of the Middle Ordovician sequence, are principally rather fine-textured, and seem to be on-shore facies of fine-textured calcilutites. There are a few dolomitites that are clearly the result of metasomatism of calcitites. Particularly important in stratigraphic studies are many metabentonites, altered volcanic ash beds, some persisting over great areas and giving exceptional recognizable horizons of synchroneity;[8] chertification of underlying beds is common.

Chemical analyses of the limestones in many of the areas have been summarized,[9] but there have been very few systematic studies of the mineralogy of the outcrop sections[10] and, excepting in West Virginia,[11] of the wells.

Classification

Rocks younger than the Canadian or Beekmantownian and older than the Cincinnatian series are commonly referred to the Middle Ordovician, and placed in two series, the Chazyan and Mohawkian, but it is proposed that the latter be divided. The Chazyan as originally defined[12] included the Black River group as well as the Chazy; but the name should be restricted to the latter. The Chazyan has two groups; the Chipman, present in Vermont and southeastern Quebec, is thought older than the base of the Chazy limestone in New York, correlated with the Maquam group of Vermont.[13] The Mohawkian series originally included[14] the higher Black River Lowville ("Birdseye") and Chaumont ("Black River" restricted) limestones and the Trenton limestone; but the older Pamelia limestone is a part of the defined Black River.[15] Black River and Trenton formations in New York and Ontario lie with regional unconformity on the Chazyan, Canadian, Upper Cambrian, and pre-Cambrian.

[8] Lawrence Whitcomb, "Correlation by Ordovician Bentonite," *Jour. Geol.*, Vol. 40 (1942), pp. 522–34.

R. R. Rosenkrans, "Stratigraphy by Ordovician Bentonite Beds in Southwestern Virginia," *Virginia Geol. Survey Bull. 46* (1936), pp. 85–111.

[9] M. F. Goudge, "Limestones of Canada, Their Occurrence and Characteristics; Pt. 4, Ontario," *Canada, Mines Br., Pub. 781* (1938). 362 pp.

B. L. Miller, "Limestones of Pennsylvania," *Pennsylvania Geol. Survey, 4th Ser., Bull. M 20* (1934). 729 pp.

J. B. McCue, J. B. Lucke, and H. P. Woodward, "Limestones of West Virginia," *West Virginia Geol. Survey*, Vol. 12 (1939). 560 pp.

B. N. Cooper, "Industrial Limestones and Dolomites in Virginia: New River-Roanoke River District," *Virginia Geol. Survey Bull. 62* (1944). 98 pp.

[10] D. R. Derry, "Heavy Minerals of the Ordovician Sediments of Ontario," *Jour. Sed. Petrology*, Vol. 4 (1934), pp. 83–88.

[11] J. H. C. Martens, "Petrography and Correlations of Deep-Well Sections in West Virginia and Adjacent States," *West Virginia Geol. Survey*, Vol. 11 (1939). 255 pp.

[12] A. W. Grabau, "A Revised Classification of the North American Paleozoic," *Science*, Vol. 27 (1909), pp. 351–56.

[13] Marshall Kay and W. M. Cady, "Ordovician Chazyan Classification in Vermont," *Science*, Vol. 105 (1947), p. 601.

[14] J. M. Clarke and Charles Schuchert, "The Nomenclature of the New York Series of Geologic Formations," *Science*, Vol. 10 (1899), pp. 874–78.

[15] Lardner Vanuxem, *Geology of New York*, Pt. III, Albany (1842), pp. 24–60.

The original Trenton[16] had practically the content of present usage, though subsequently the name was applied to a period including the "Chazy," "Birdseye," "Black River," and "Trenton" epochs, and later the "Trenton," "Utica," and "Hudson" epochs.[17] The Trenton came to be classed as a series, the Trentonian,[18] containing essentially the rocks of the original usage. The Chazy, Black River, and Trenton commonly have been classed as groups of the Middle Ordovician. They are comparable in stratigraphic magnitude, and are separated by persistent regional unconformities. The term Black River does not lend itself to conversion to a series name (Black Riverian), for it is not mononomial, nor do the two words blend euphoniously. The advantage of renaming the series from New York or Ontario would be that relations to Chazyan and Trentonian are directly determinable.

The Lincolnshire limestone is the probable though not a certain correlative in the Appalachian region of the higher Chazyan of Lake Champlain. It is succeeded with regional unconformity by a sequence that includes the Black River equivalents, and disconformably underlies the Nealmont formation and correlatives that are lower Trentonian. The sequence may include post-Chazyan older than Pamelia, and pre-Trentonian younger than Chaumont; the rocks as a whole are more fossiliferous because deposited in a less restricted marine environment; thus a term from the Appalachian area has advantages. Bolarian series has been proposed for this sequence,[19] from Bolar Valley in Highland and Bath counties, Virginia; the consonants incidentally are the abbreviation of Black River. Although no single locality is known to have a complete section of the series, most stages are represented in exposures in the valley, which lies in an intermediate position among the Pennsylvania-eastern West Virginia, Appalachian Valley, and southwestern Virginia sequences. The Bolarian series is thought to occupy the Chazyan to Trentonian interval; in any case it is a useful provincial series.

The stratigraphic units east of the Allegheny synclinorium are classified in the following provincial time-stratigraphic divisions.

Upper Trentonian	
Middle Trentonian	
Lower Trentonian	
Upper Bolarian	Hunterian
Lower Bolarian	Hatterian
Upper Chazyan	Lincolnshirian
Lower Chazyan	"Blackford-Five Oaks"

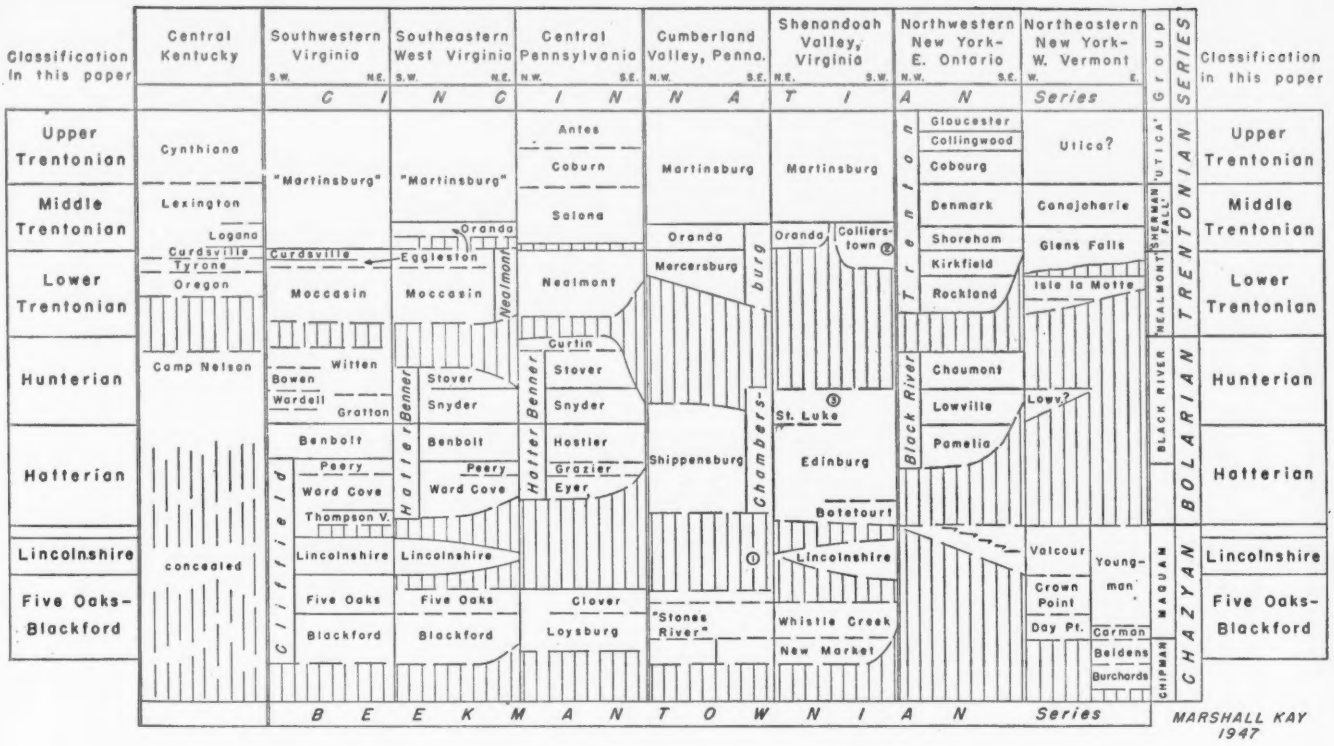
The units are subseries or groups excepting that the "Blackford-Five Oaks" are formations that are utilized for informal time-stratigraphic reference, and the

[16] T. A. Conrad, "Second Annual Report on the Paleontological Department of the Survey," *New York Geol. Survey* (1839), p. 63.

[17] J. D. Dana, *Manual of Geology* (1865), p. 205; *ibid.*, 4th ed. (1894), p. 489.

[18] A. W. Grabau, *op. cit.* (1909).

[19] Marshall Kay, "Bolarian Series of the Ordovician" (abstract), *Bull. Geol. Soc. America*, Vol. 59 (1947), pp. 1198–99.



① "Lowville" of Marion, Pennsylvania, considered possibly Lincolnshire—Cooper and Cooper.
② "St. Luke" of Lexington, Virginia, considered to be Collierstown-Eggleston—Kay.
③ St. Luke correlated with Witten—Cooper and Cooper; top Edinburg "possibly early Trenton", included Mercersburg of Pennsylvania.

FIG. 2.—Classification of sections along Allegheny synclinorium.

Lincolnshirian a stage-formation unit. The classification of the named rock units in sequences in the region is summarized in the correlation table (Fig. 2). The discussion of the subseries includes the stratigraphic relations, thicknesses, and lithologic characters thought most relevant to the problems of the subsurface of the Allegheny synclinorium. The maps do not show paleogeographic relations correctly, for they are not on palinspastic base maps.[20]

The stratigraphy of the formations in sections along the margin of the synclinorium has been described in publications on Ontario and New York,[21] central Pennsylvania,[22] and southwestern Virginia.[23] A discussion of the rocks in the Appalachian Valley in northern Virginia[24] is important for regional understanding. A similar study of the Cumberland Valley in Pennsylvania and Maryland is in preparation[25] and the writer is engaged in the stratigraphic problems from the New River to central Pennsylvania.[26]

The older reports and maps are indispensable in showing the distribution of belts of outcrop and exposures, but the rock units are not consistently named, even within small areas. Charles Butts published several maps and reports on central Pennsylvania[27] and the state geologic map has additional unpublished

[20] Marshall Kay, "Paleogeographic and Palinspastic Maps," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 29 (1945), pp. 426–50.

[21] Marshall Kay, "Stratigraphy of the Trenton Group," *Bull. Geol. Soc. America*, Vol. 48 (1937), pp. 233–301.
———, "Ottawa-Bonnechere Graben and Lake Ontario Homocline," *ibid.*, Vol. 53 (1942), pp. 585–646.
F. P. Young, Jr., "Black River Stratigraphy and Faunas," *Amer. Jour. Sci.*, Vol. 241 (1943), pp. 141–66; 209–40.

[22] Marshall Kay, "Chemical Lime in Central Pennsylvania," *Econ. Geol.*, Vol. 38 (1943), pp. 188–203.
———, "Middle Ordovician of Central Pennsylvania," *Jour. Geol.*, Vol. 52 (1944), pp. 1–23; 97–116.

[23] B. N. Cooper and C. E. Prouty, "Stratigraphy of the Lower Middle Ordovician of Tazewell County, Virginia," *Bull. Geol. Soc. America*, Vol. 54 (1943), pp. 819–86.
B. N. Cooper, "Geology and Mineral Resources of the Burkes Garden Quadrangle, Virginia," *Virginia Geol. Survey Bull. 60* (1944). 299 pp.
———, "Industrial Limestones and Dolomites in Virginia: New River-Roanoke River District," *ibid., Bull. 62* (1944). 98 pp.
G. G. Huffman, "Middle Ordovician Limestones from Lee County, Virginia to Central Kentucky," *Jour. Geol.*, Vol. 53 (1945), pp. 145–74.
C. E. Prouty, "Lower Middle Ordovician of Southwest Virginia and Northeast Tennessee," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 30 (1946), pp. 1140–91.

[24] B. N. Cooper and G. A. Cooper, "Lower Middle Ordovician Stratigraphy of the Shenandoah Valley, Virginia," *Bull. Geol. Soc. America*, Vol. 57 (1946), pp. 35–114.

[25] L. C. Craig, "Middle Ordovician of the Chambersburg Region" (abstract), *Bull. Geol. Soc. America*, Vol. 53 (1942), pp. 1963–64.

[26] Marshall Kay, "Middle Ordovician Limestones in Southeastern West Virginia and Adjacent Virginia" (abstract), *ibid.*, Vol. 57 (1946), p. 1210.

[27] Charles Butts and E. S. Moore, "Geology and Mineral Resources of the Bellefonte Quadrangle, Pennsylvania," *U. S. Geol. Survey Bull. 855* (1936). 111 pp.
Charles Butts, F. M. Swartz, and Bradford Willard, "Tyrone Quadrangle," *Pennsylvania Geol. Survey Atlas 96*, 4th Ser. (1939). 118 pp.
Charles Butts, "Hollidaysburg-Huntingdon Quadrangles," *U. S. Geol. Survey Atlas 26* (1946). 16 pp.

FIG. 2.—Classification of sections along Allegheny synclinorium.

information.[28] The West Virginia outcrop is discussed and mapped in two volumes of the county report series.[29] The entire area of outcrop in Virginia is contained in the map of the Appalachian Valley,[30] and much detail on exposures in the subsequent report on the geology of the valley.[31]

CHAZYAN SERIES

BLACKFORD AND FIVE OAKS

Lithologic character and thickness.—The Blackford[32] consists of the three lowest zones of the Middle Ordovician in Tazewell County, Virginia: the basal clastics, ash gray shale, and blocky chert;[33] the Five Oaks[34] is the succeeding first calcilutite zone; each is a formation. The thickness of the combined units is variable because of their overlapping an erosion surface on the Canadian with relief of 100 feet or more in local areas; the Blackford is found to reach as much as 300 feet. The Five Oaks is also quite variable, ranging from virtual absence to several hundred feet thick for reasons not recorded. An isopachous map has not been prepared.

The typical three-fold division of the Blackford is extensive southwestward. On the northeast the formation becomes principally fine- to medium-crystalline dolomitite in the lower part, readily separable from the similar Canadian as far as southern Highland County by persistence of angular chert conglomerate at the base; northeastward, where conglomerate is missing, the Canadian and Blackford are relatively inseparable. The upper Blackford is of calcilutite with nodular to well bedded black chert. The Five Oaks persists as an almost pure calcilutite. The Loysburg formation of central Pennsylvania, with the Clover calcilutite as the top member, is similar to the Blackford-Five Oaks; basal relations have not been ascertained satisfactorily.

Subsurface prospects.—The persistence of the Five Oaks and Clover limestones as pure calcilutites, contrasting with the cherty dark Lincolnshire limestone or silty argillaceous Hatterian formations, should make the upper surface of the

[28] G. W. Stose and O. A. Ljungstedt, "Geologic Map of Pennsylvania," *Pennsylvania Topog. and Geol. Survey* (1931).

[29] J. L. Tilton, W. F. Prouty, and P. H. Price, "Pendleton County," *West Virginia Geol. Survey* (1927). 384 pp.
D. B. Reger and P. H. Price, "Mercer, Monroe and Summers Counties," *ibid.* (1926). 963 pp.

[30] Charles Butts, "Geologic Map of the Appalachian Valley of Virginia with Explanatory Text," *Virginia Geol. Survey Bull. 42* (1933). 56 pp.

[31] Charles Butts, "Geology of the Appalachian Valley in Virginia, Part I—Geologic Text and Illustrations, 1940; and Part II—Fossil Plates and Explanations, 1941," *ibid., Bull. 52* (1942). 568 pp. and 271 pp.

[32] Charles Butts, *ibid.*, p. 126.

[33] B. N. Cooper and C. E. Prouty, "Stratigraphy of the Lower Middle Ordovician of Tazewell County, Virginia," *Bull. Geol. Soc. America*, Vol. 54 (1943), pp. 823–26.
B. N. Cooper, "Geology and Mineral Resources of the Burkes Garden Quadrangle, Virginia," *Virginia Geol. Survey Bull. 60* (1944), pp. 36–40, 55–58.

[34] B. N. Cooper and C. E. Prouty, *op. cit.*, p. 863.

Five Oaks-Clover a recognizable datum. In much of the area, the dolomitite of the Blackford is so like that of the Canadian that the two may be difficult to separate; and where separation is possible, the surface is one of erosional relief, not desirable for structural control. In the southern part of the synclinorium, the youngest persistent dolomitites are in the Blackford and Loysburg.

LINCOLNSHIRIAN

Lithologic character and thickness.—The Lincolnshire[35] comprises about 100 feet of dark, irregularly bedded, black-chert-bearing limestone, the *Sowerbites* beds, in Tazewell County, Virginia, and its equivalents. The formation persists in northwestern belts from Tennessee to Pendleton County, West Virginia, and in the Appalachian Valley northward to the West Virginia boundary. It has been correlated with the upper Lenoir of Tennessee,[36] and on the other hand stated to be "considerably above true Lenoir equivalents in the Blackford formation."[37] The writer believes the Lincolnshire to be upper Chazyan on the bases of stratigraphic position, the presence of the overlying regional unconformity, and fossils not known in younger beds, but Cooper and Cooper[38] reported it "younger than typical Chazy by reason of strong dissimilarity of fossils"; "the Lincolnshire and the *Tetradium cellulosum* beds [at Marion, Pennsylvania] appear to have the same stratigraphic position," and "if definite correlation can be established, the post-Chazy age of the Lincolnshire will be positively affirmed."

The Lincolnshire is persistent as a unit of less than 200 feet over a great area (Fig. 3), the maximum of about 300 feet being in the Appalachian Valley in Rockbridge County, near Lexington, Virginia. Dark, black-chert-bearing, medium-textured limestone prevails, but calcarenite is common, and there are some bioherms with white calcilutite near the top. The beds thin gradually northward along the margin of the synclinorium to 30 feet in Pendleton County, northwest of Franklin, West Virginia, and seem absent in Pennsylvania; the limestone is calcarenite in the thinnest sections.

Subsurface prospects.—The Lincolnshire terminates northeastward along the eastern margin of the synclinorium in the 90-mile gap between Pendleton County, West Virginia and Bedford, Pennsylvania. Though it also disappears in the Appalachian Valley near the West Virginia boundary,[39] there seems no basis for postulating the course of the pinch-out under the synclinorium, nor evidence that it is of facies other than that of the outcrop. Thus the limit shown on the isopachous map is not adequately controlled.

[35] B. N. Cooper and C. E. Prouty, *ibid.*, p. 863.

[36] C. E. Prouty, "Lower Middle Ordovician of Southwest Virginia and Northeast Tennessee," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 30 (1946), p. 1152.

[37] B. N. Cooper and G. A. Cooper, "Lower Middle Ordovician of the Shenandoah Valley, Virginia," *Bull. Geol. Soc. America*, Vol. 57 (1946), p. 77.

[38] B. N. Cooper and G. A. Cooper, *ibid.*, pp. 77–78.

[39] B. N. Cooper and G. A. Cooper, *ibid.*, p. 70.

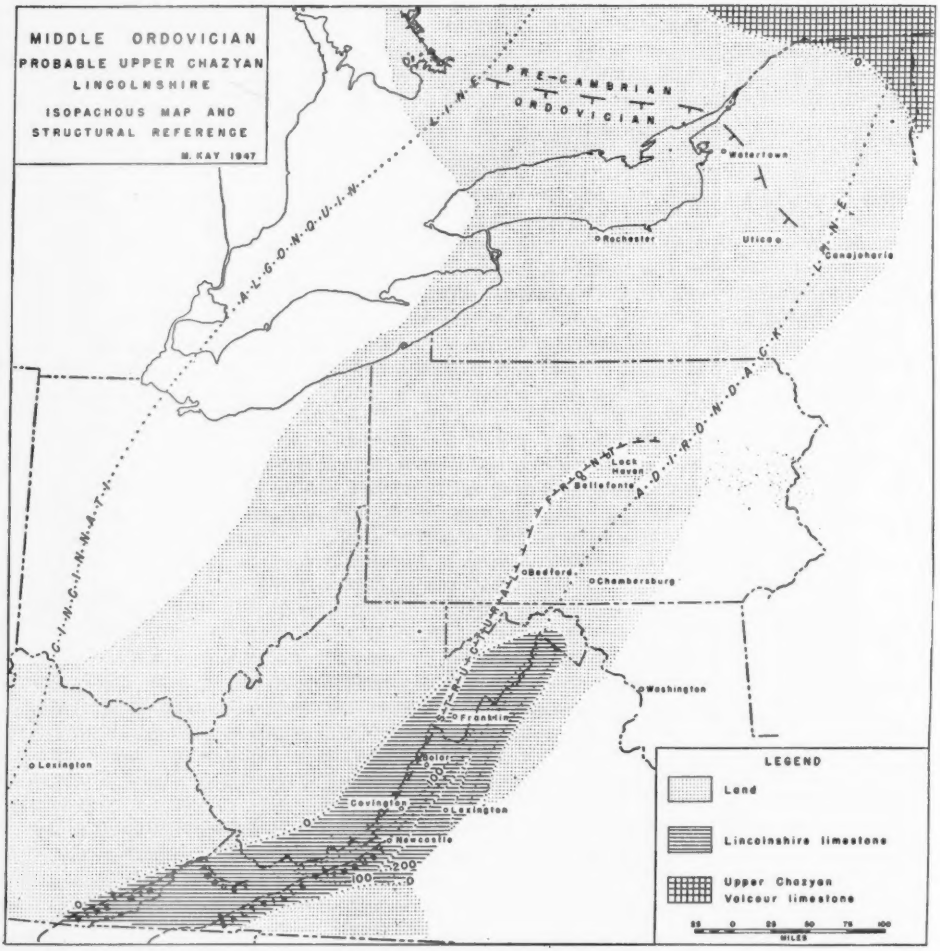


FIG. 3.—Structural reference and isopachous map of Lincolnshirian.

BOLARIAN SERIES

HATTERIAN

Classification.—The rocks between the Lincolnshire limestone, or in its absence the Five Oaks or Clover calcilutite, and the top of the Hostler, or the correlated Benbolt impure limestone, form a rather constant time-stratigraphic unit that loses older beds northward along the east side of the synclinorium. The

name Hatter was applied to the rocks in this sequence in Pennsylvania as a formational name.[40] Subsequently the Hatter was divided into three members. Eyer, Grazier, and Hostler;[41] these can be classed as formations in a group. At about the same time, the Ward Cove, Peery, and Benbolt formations were described in Tazewell County, Virginia, the first two assigned to the Clinfield group.[42] Relations of the two sequences were not considered; the three Virginia units are thought to be represented in the Hatter, though the lower incompletely. There being no other comparably inclusive term, it is proposed that the Hatter be considered a group or subseries comprising rocks younger than the post-Lincolnshire regional unconformity, and older than the top of the Hostler and Benbolt formations, thought essentially synchronous. The Hatterian forms the lower and older part of the Bolarian series-epoch. The writer stated[43] the Hatter to lie beneath rocks "correlated with confidence with the Pamelia limestone" and to be "older than the base of the standard Black River," "younger than Chazyan, equivalent to some part of the Chazyan, or both"; he subsequently concluded that his confidence was misplaced, and that the lithologic similarity of the overlying Snyder and Stover to the Lowville and Chaumont of New York was probably more significant than contradictory faunal evidence.[44] Faunas of the formations are so related to lithologic character that the upper Chazyan of Vermont and New York has faunal elements resembling some in Hostler,[45] Ward Cove, and Lincolnshire of comparable lithofacies; the interpreted stratigraphic continuity of Hatter with Pamelia implies that it is post-Chazyan, and the disconformable relationship of Ward Cove to Lincolnshire, while essentially conformable with younger Hatterian, supports its placement in the same group and series.

Lithologic character and thickness.—The Hatterian rocks show marked changes in lithologic character and thickness (Fig. 4), though principally southeast of the outcrops margining the synclinorium. Most of the Edinburg formation of the Shenandoah Valley,[46] and most of the Shippensburg limestone of the Cumberland Valley, Pennsylvania,[47] are Hatterian. The Shippensburg thickens from less than 50 feet to more than 500 in a few miles in Pennsylvania, and from about 400 to

[40] Marshall Kay, "Middle Ordovician of Central Pennsylvania" (abstract), *Bull. Geol. Soc. America*, Vol. 52 (1941), p. 969.

[41] Marshall Kay, "Chemical Lime in Central Pennsylvania," *Econ. Geol.*, Vol. 38 (1943), p. 193.

[42] B. N. Cooper and C. E. Prouty, *op. cit.*, pp. 863, 868.

[43] Marshall Kay, "Middle Ordovician of Central Pennsylvania," *Jour. Geol.*, Vol. 52 (1944), pp. 11–12.

[44] Marshall Kay, "Middle Ordovician of Southeastern West Virginia and Adjacent Virginia" (abstract), *Bull. Geol. Soc. America*, Vol. 57 (1946), p. 1210.

[45] A faunule listed as from the Eyer (Marshall Kay, *op. cit.* (1944), table 2, p. 12, locality 1 *only*) is, excepting for *Tetradium fibratum* Safford, from the Hostler.

[46] B. N. Cooper and G. A. Cooper, *op. cit.*, p. 86.

[47] L. C. Craig, "Middle Ordovician Limestone of the Chambersburg Region, Pennsylvania" (abstract), *Bull. Geol. Soc. America*, Vol. 53 (1942), p. 1963.

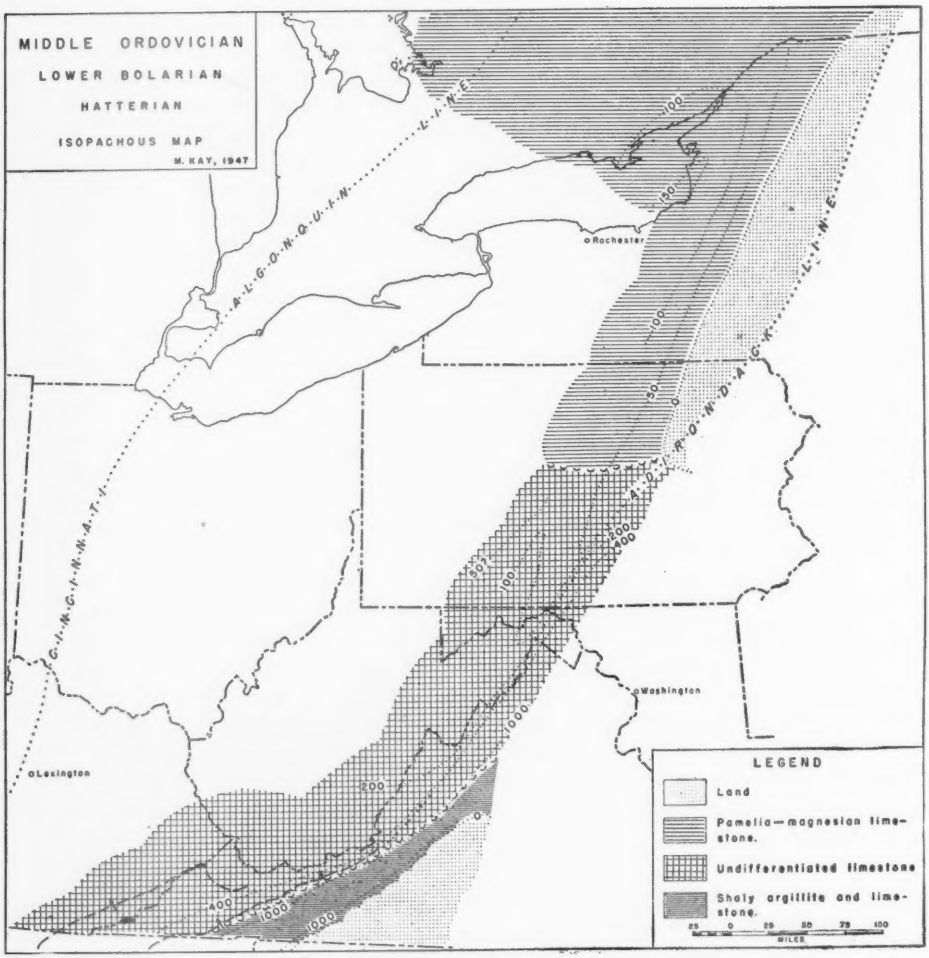


FIG. 4.—Lower Bolarian (Hatterian) isopachous and paleolithologic map.

1,000 feet in Virginia, increasing southeastward. These increases are across the Adirondack line and the Saltville thrust. Normal to these and parallel with the line, the Hatterian thins gradually northeastward, from about 1,500 feet south of the Saltville thrust to about 500 feet in the Cumberland Valley; and from approximately 400 feet in southeastern West Virginia along the structural front to 200 feet in Pendleton County, and less than 100 in central Pennsylvania. The thinning in the valley belts seems to be by convergence, whereas in the Allegheny belt, it is considerably by overlap, which moreover continues normal to and to-

ward the Adirondack line in Pennsylvania. The maximum of Pamelia limestone in New York, 150 feet, is somewhat greater than that of the Hatterian of Pennsylvania.

The Hatterian in the Allegheny belt has a great variety of calcareous facies, ranging from calcargillutites in the thicker Ward Cove sections to quartz-arenaceous and argillaceous shaly limestones in the Hostler of Pennsylvania; and from black-cherty calcilutite in the Peery to biohermal argillaceous limestone in some of the Benbolt. As a whole it is more argillaceous and laminated in the thicker and lower sections and toward the southeast. The subseries is preponderantly argillite in the southern and eastern sections beyond the Adirondack line, becoming quartz-sandy in the Athens of Tennessee, in proximity to the land, Blountia, raised in the Carolina-Georgia area during its deposition.

Subsurface prospects.—The lower Hatterian, particularly the Ward Cove shaly argillicalcilutite, is quite carbonaceous in many areas. The Hostler formation in central Pennsylvania is typically quartz-sandy and silty, silica comprising as much as a fourth of the rock. Inasmuch as the facies farther northeast in the outcrop has little quartz sand, it is possible that the unit passes into more quartz-sandy facies toward the northwest. It is the most siliceous rock unit in the Middle Ordovician in central Pennsylvania, and contrasts strongly with relatively pure calcilutite in the underlying Clover and overlying Hunterian.

HUNTERIAN

Classification.—The Hunter group[48] includes the Snyder, Stover, and Curtin limestones of central Pennsylvania,[49] the first two described as members of the Benner formation. The Hunterian subseries is of rocks younger than the base of the Snyder, and older than the unconformity separating the Curtin and lower Trentonian Nealmont limestone; inasmuch as the Curtin is thickening northwestward beneath an unconformity as it passes beneath the Appalachian Plateau, there are Hunterian sediments younger than those exposed. The name is from Hunter Park, on the Bellefonte Central Railroad in Centre County, Pennsylvania. If it be correct that the Benbolt of southwestern Virginia is the time-equivalent of the Hostler of Pennsylvania, and the higher Witten *Camarocladia* zone corresponds with the Stover, the Gratton, Wardell, Bowen, and Witten are Hunterian. The Benner has been correlated "on stratigraphic position and the range of *Cryptophragmus antiquatus* Raymond" with the Pamelia.[50] But the "rather constant lithology" of the Snyder and Stover "from Virginia to north-central Pennsylvania and similarity to Lowville and Chaumont in New York suggest equivalence, contrary to previous faunal interpretations."[51]

[48] Marshall Kay, "Bolarian Series of the Ordovician" (abstract), *Bull. Geol. Soc. America*, Vol. 59 (1947), pp. 1198–99.

[49] Marshall Kay, *op. cit.* (1941), p. 969.
———, *op. cit.* (1943), pp. 192–94.

[50] Marshall Kay, *op. cit.* (1944), p. 23.

[51] Marshall Kay, *op. cit.* (1946), p. 1210.

Lithologic character and thickness.—Along the eastern and northeastern sides of the Allegheny synclinorium, the Hunterian has a lower unit (Snyder-Lowville) principally of impure calcilutite, with intercalated calcarenite and calcilutite-pebble conglomerate, an upper unit (Stover-Chaumont) of fucoidal dark dense resistant calcilutite, and in a limited area in Pennsylvania an uppermost pure calcilutite (Curtin); these are of greatest thickness, more than 300 feet, in central Pennsylvania. In southwestern Virginia, the higher part of the Witten limestone, the *Camarocladia* beds, is like the Stover, and the Gratton limestone, Wardell formation, Bowen formation, and lower Witten limestone, of maximum thickness of nearly 300 feet, have the stratigraphic position of the thinner Snyder, if the Hostler and Benbolt are correctly correlated; the southwestern Virginia sequence has more varied lithologic types, and includes the Wardell fossiliferous calcareous argillite.

The Hunterian thicknesses are summarized on the isopachous map (Fig. 5). The rocks seem to thin east-southeastward, so that they diminish along the structural front from Pennsylvania to southeastern West Virginia where the trend is more southerly, and increase as the trend becomes more westerly toward southwestern Virginia. The decrease southeastward in Pennsylvania is through truncation possibly in part by offlap, so that only the lower Hunterian is present east of the Adirondack line in southern Pennsylvania and northern Virginia—the St. Luke limestone in the latter area. In southeastern West Virginia, the decrease seems to be by convergence as well as offlap or truncation, and the group is absent in anticlines in Virginia southeast of those along the structural front. In southwestern Virginia, the subseries is missing in the southernmost belts, pre-Hunterian being overlain by lower Trentonian. There seems to be some convergence northwestward into central Kentucky.[52]

Subsurface prospects.—The Hunterian will be found in maximum thickness in the Allegheny synclinorium—in fact, may be thicker than along the outcrop. Variations in its thickness may result from post-Bolarian—pre-Trentonian erosion, for there are significant channels in the Pennsylvania exposures. The upper Hunterian should have the thickest and purest calcilutite in the subsurface section; but it is probable that the rocks are more shaly and fossiliferous, inasmuch as the axis of the seaway probably passed west of the present outcrop. The only sands of consequence in the sections are in the Bowen formation in southeastern Virginia; these came from the southeast, and presumably do not extend far into the southern part of the synclinorium. The Stover limestone is difficult to separate lithologically from the lower Trenton Nealmont in areas where they adjoin on the outcrop, but they should be separated in Pennsylvania by the highest principal calcilutite, the Curtin; however, as there is calcilutite of tens of feet in the Nealmont in eastern West Virginia, in an area lacking Curtin, identification will depend on careful lithologic studies.

[52] G. G. Huffman, "Middle Ordovician Limestones from Lee County, Virginia, to Central Kentucky," *Jour. Geol.*, Vol. 53 (1945), pp. 170–71.

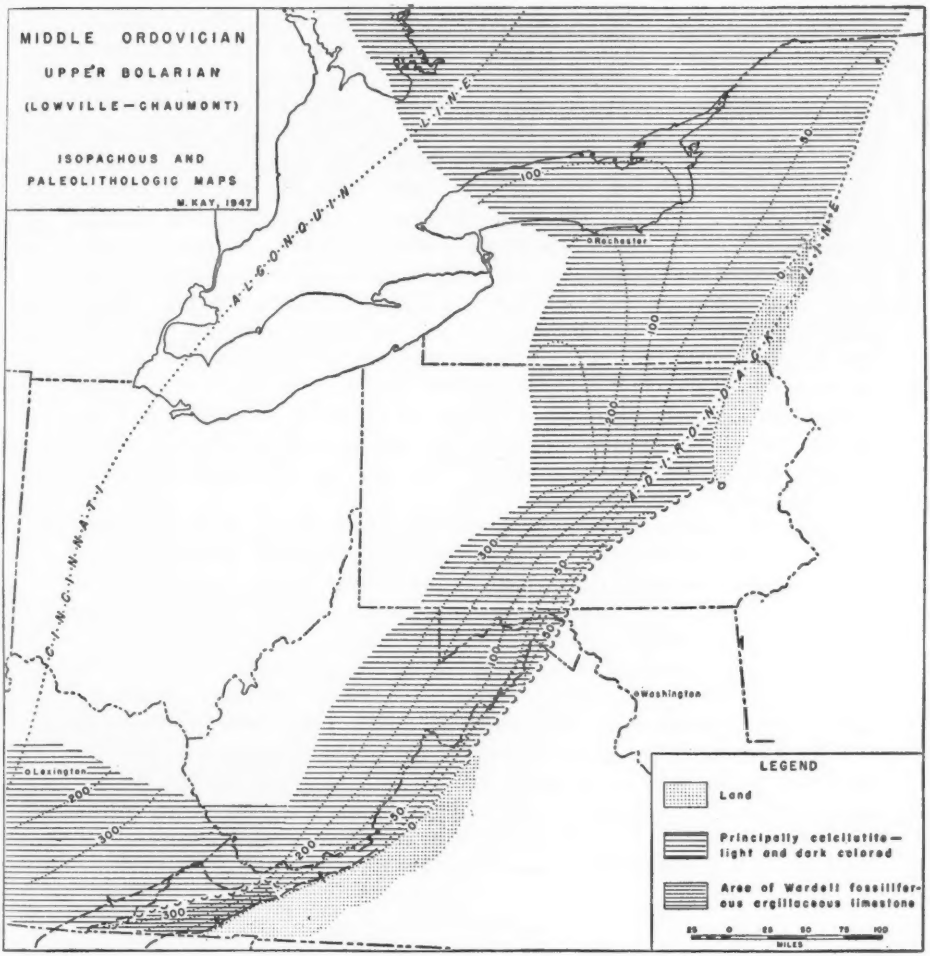


FIG. 5.—Upper Bolarian isopachous and paleolithologic map.

TRENTONIAN SERIES

LOWER TRENTONIAN

The lower Trentonian formations of northwestern New York and eastern Ontario, the Rockland and Kirkfield or Hull limestones, disconformably overlap Black River rocks, lying locally on Canadian and Cambrian along the Mohawk River, and on pre-Cambrian in Ontario; the Rocklandian and Kirkfieldian are

considered to be stages. In central Pennsylvania, the Nealmont[53] formation is equivalent, and the subseries in the Appalachians is referred to as the Nealmontian, extending from the base of the Trentonian. The Nealmont intertongues southward in southeastern West Virginia through several facies into the Moccasin reddish and the Eggleston buff calcareous argillites (Fig. 6); they become argillaceous calcilutites in extreme southwestern Virginia, the upper part of the Eggleston becoming the Curdsville fossiliferous shaly limestone. The Nealmontian includes the Oregon, Tyrone, and Curdsville limestones in Kentucky.[54] Two most prominent metabentonites in the Nealmont of Pennsylvania, N1 and N2, may correspond with two in eastern West Virginia and adjoining central-western Virginia; a similar pair, the Pencil Cave and Mud Cave clays in western Virginia and central Kentucky, seem in about the same stratigraphic position; they have been correlated with clays V4 and V7 of Virginia,[55] but there are anomalies in this classification that have not been resolved. The Mercersburg limestone of the Cumberland Valley, southern Pennsylvania, east of the Adirondack line, is an eastern correlative of the Nealmont;[56] the unit may be absent in western belts in northern Virginia, the late Bolarian St. Luke directly underlying the medial Trentonian Oranda limestone.[57]

The lower Trentonian thicknesses are summarized in an isopachous map (Fig. 6). The maximum thickness in New York and Ontario is near Watertown, about 150 feet. The diminution westward and eastward is partly by overlap, and there are intervals of non-deposition within the subseries as it approaches its disappearance at Canajoharie on the Adirondack line at the Mohawk River. In general, there is southward divergence along the axis of maximum thickness. In Pennsylvania, there is similar overlap on a regional unconformity toward the southeast to a minimum at the Adirondack line in Path Valley northwest of Chambersburg, and divergence in the Mercersburg limestone beyond. In the Bellefonte district there are abrupt variations because of overlap on an unconformity of local relief of tens of feet. Within the area of outcrop in this region, there is an isopachous trough[58] that may be the filling of a subsequent valley within a cuesta of Curtin limestone, rather than a continuation of the Rideauan

[53] Marshall Kay, *op. cit.* (1941), p. 1969.

[54] G. G. Huffman, *op. cit.* (1945), pp. 158–62, 167–69.

[55] R. R. Rosencrans, "Stratigraphy of Ordovician Bentonite Beds in Southwestern Virginia," *Virginia Geol. Survey Bull. 46* (1936), pp. 85–112.
G. G. Huffman, *op. cit.* (1945), pp. 158–60.

[56] L. C. Craig, "Middle Ordovician of the Chambersburg Region" (abstract), *Bull. Geol. Soc. America*, Vol. 53 (1942), pp. 1963–64.

[57] B. N. Cooper and G. A. Cooper, "Lower Middle Ordovician Stratigraphy of the Shenandoah Valley, Virginia," *ibid.*, Vol. 57 (1946), pp. 59, 81–82, 86.

[58] Marshall Kay, *op. cit.* (1944), p. 99.

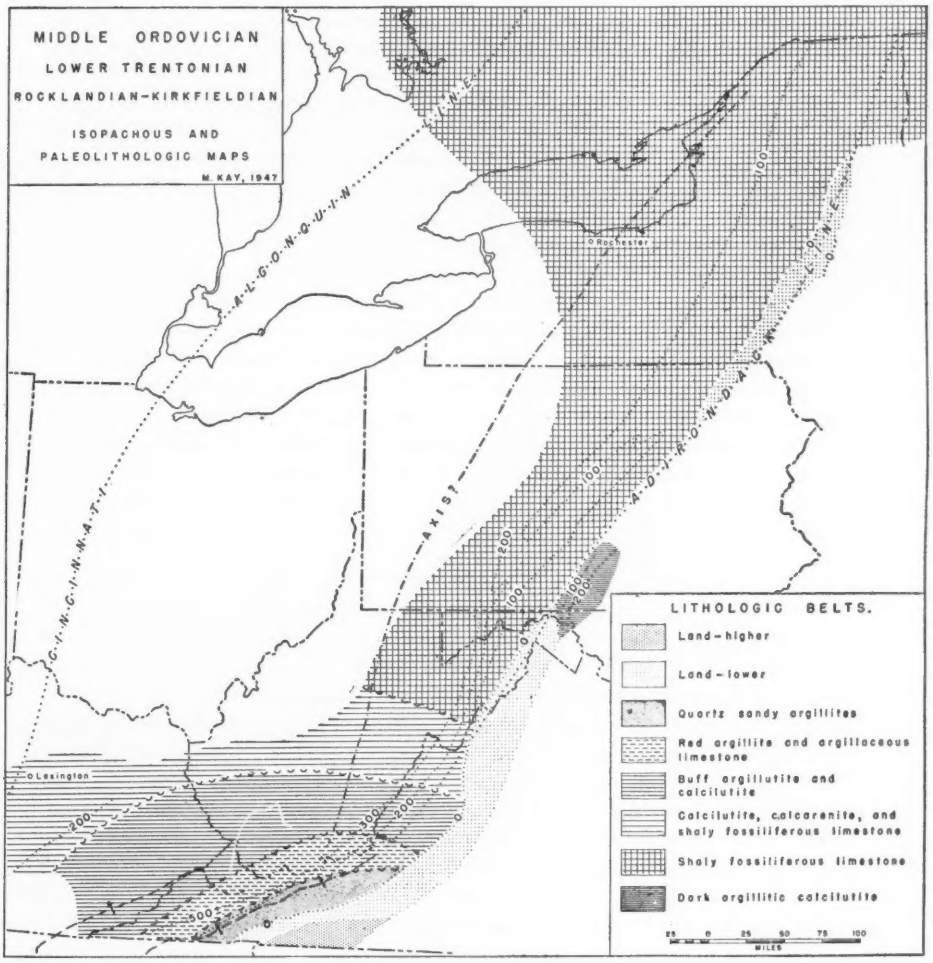


FIG. 6.—Lower Trentonian isopachous and paleolithologic map.

trough from New York; hence, the axis of maximum thickness may be west of the structural front. There is thickening by divergence southwestward into eastern West Virginia.

The Moccasin and Eggleston (and Collierstown) thin by convergence and overlap southeastward in calcareous facies from southeastern Virginia; and by

overlap southward in argillaceous facies in southwestern Virginia in sections some distance south of the structural front. They converge from southwestern Virginia to central Kentucky.[59]

Subsurface prospects.—The Nealmontian may form a thick isopachous tongue with the axis within the Allegheny synclinorium. The lowest beds in New York, the Selby member of the Rockland, are bituminous, and there are petroliferous vugs in the higher Rockland in northwestern New York. However, the basal beds above the contact with the Black River, Bolarian, are nowhere quartz-sandy, commonly being of calcarenite overlying a stylolitic parting on denser calcilutitic limestone. Similarly, the Nealmont limestone in the deep channels in the Curtin limestone in the Bellefonte mining district is of coarse calcarenite, crystalline and relatively impervious. Farther south, the basal Nealmontian is impure and shaly limestone, commonly concealed at the contact with the Stover dark calcilutite. Throughout the northern half of the region, the Rocklandian is commonly more massive, the Kirkfieldian more argillaceous and shaly, so that in outcrop and wells, the base of the Kirkfieldian is recognized readily, but that of the massive Rocklandian resembles the massive Hunterian. The base of the Kirkfieldian thus is commonly considered the Black River-Trenton contact in wells, being the most readily determinable horizon of lithologic contrast.[60]

MIDDLE TRENTONIAN

The middle Trentonian includes rocks equivalent to the Shoreham and Denmark limestones of New York, or the undivided Sherman Fall limestone. The Shorehamian, marked by the first appearance of *Cryptolithus tesselatus* Green in New York and Ontario, has been recognized in the lower part of the Salona limestone of central Pennsylvania and eastern West Virginia, and in the Oranda limestone of the Cumberland and Shenandoah valleys, the "*Christiania*" beds of the "Chambersburg limestone." There is a possibility that the uppermost Eggleston and Collierstown beds are of this age, though the evidence has not been presented. The lower "Hermitage" limestone of southwestern Virginia, and the Logana limestone of central Kentucky have been included in the stage. The lower Denmarkian commonly has abundance of *Sinuites cancellatus* (Hall), but the upper limit has been established only in New York and Ontario, where succeeded by the late Trentonian Cobourg limestone; in central Pennsylvania, the Salona is overlain by the Coburn limestone, the contact approximating the top of the Denmarkian. Thus, the thickness of middle Trentonian west of the Adirondack line can be compiled only in limited areas.

The Shorehamian is of limestone throughout its extent, being generally more argillaceous than the subjacent Kirkfieldian, particularly east of the Adirondack line. The Denmarkian has limestones west of the line, which have been shown to

[59] G. G. Huffman, *op. cit.* (1946), pp. 170–72.

[60] G. V. Cohee, "Cambrian and Ordovician in Recent Wells in Southeastern Michigan," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 31 (1947), p. 299.

change through a succession of facies into the Canajoharie black shale as they thicken and approach the Adirondack line in New York;[61] the thickening increases greatly, and the beds become sandy (Schenectady) along the lower Mohawk River. The Salona is dark, dense, carbonaceous limestone like one of the intermediate facies west of the line in New York; the Martinsburg of the Cumberland and Shenandoah valleys is principally of facies like the Canajoharie. The Salona converges toward the line from the northwest; the stratigraphy east of the line has not been ascertained. South of eastern West Virginia in the western belts, the middle Trentonian limestones become more calcarenitic, resembling a facies farther from the line in New York.

Subsurface prospects.—The middle Trentonian shale is argillaceous and carbonaceous if not bituminous east of the Adirondack line, and the carbonaceous dense platy limestone forms a belt west of the line from the vicinity of Utica, New York, to an area west of the structural front in central Pennsylvania and eastern West Virginia. The facies may have been a source of petroleum in the past, and there were originally calcite sandstones on the west, though these are not obviously porous along the present outcrop.

UPPER TRENTONIAN

The upper Trentonian includes the Cobourg limestone and disconformably overlying Holland Patent shale in northwestern New York, the latter passing into the Collingwoodian calcareous shale and Gloucesterian black shale, mapped also as the Billings and Eastview formations in Ontario. The Cobourg and Holland Patent become the Utica black shale eastward, the change in facies and nature of stratigraphic change being abrupt but somewhat obscure.[62] The only area on the southwest where there has been any separation of these higher units is in north-central Pennsylvania, where 700 feet of Coburn limestone and Antes black shale have been correlated. The Cobourg and Coburn consist considerably of calcarenite, and were originally porous and permeable; they probably formed a facies on the west flank of a shallow, southwest-plunging arch west of the Adirondack line. The Coburn will be found to continue under the Allegheny synclinorium as the uppermost limestone of the Trentonian, and the Antes will probably be found to retain its black shale facies far westward; thus the contact, although in the middle of the upper Trentonian, is that at the top of the "Trenton lime" of drillers. The Holland Patent and Antes are commonly called "Utica" but represent only the upper third of the true Utica, most of which is Cobourgian. The Cobourgian is dolomite locally along its outcrop north of Lake Huron, and it may be so in the western Allegheny belt. It is rather constant in thickness along Lake Ontario, thinning northward by overlap. Comparison of Cobourg and Coburn suggests thickening southward by divergence in the synclinorium.

[61] Marshall Kay, "Mohawkian Series on West Canada Creek, New York," *Amer. Jour. Sci.*, Vol. 241 (1943), p. 605.

[62] Marshall Kay, *ibid.* (1943), p. 6.

CINCINNATIAN SERIES

The Cincinnatian series is an entirely different form of deposit, being detrital sediments coarsening toward the southeast, and forming a great semi-lens centered in eastern Pennsylvania, an exogeosyncline. An outline of the stratigraphy has been presented[63] though the detailed stratigraphic character in Pennsylvania is much more complex than expressed in the generalizations.

The Middle Ordovician is almost entirely limestone in the Allegheny belt, though there are thick argillites east of the Adirondack line in the lower Bolarian in Virginia, and in the middle Trentonian from Vermont to Virginia. The Upper Ordovician contrasts in being wholly clastic products from lands raised east of the region.

[63] Marshall Kay, "Development of the Allegheny Synclinorium and Adjoining Regions," *Bull. Geol. Soc. America*, Vol. 53 (1942), pp. 1614–18.

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CAMBRIAN AND ORDOVICIAN ROCKS IN MICHIGAN BASIN AND ADJOINING AREAS[1]

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ABSTRACT

Sandstone, limestone, and dolomite of Upper Cambrian and Ordovician age either are exposed at the surface or underlie glacial drift in the Northern Peninsula of Michigan. The outcrop of these rocks extends southward from northern Michigan into Wisconsin and Illinois. Eastward across the Northern Peninsula, Middle Ordovician rocks overlap progressively older rocks, and on Manitoulin and adjacent islands Black River rocks of Middle Ordovician age rest on pre-Cambrian. This same stratigraphic relationship is observed in other outcrop areas in Ontario and in deep wells that have penetrated the full section of sedimentary rocks. Pre-Black River erosion removed most of the older Paleozoic rocks from the underlying pre-Cambrian in southwestern Ontario and in some places only a thin remnant of Upper Cambrian sandstone and some dolomite occurs between Middle Ordovician and pre-Cambrian rocks.

Cambrian and Lower Ordovician ("sub-Trenton") sandstone and dolomite range in thickness from less than 500 feet to more than 3,500 feet in Michigan. The aggregate thickness of these rocks increases southwestward from Michigan toward Illinois and thins southeastward over the Findlay arch in southeastern Michigan and northwestern Ohio. The rocks increase in thickness eastward into the Appalachian basin from the Findlay arch.

The widespread limestones and dolomites of Middle Ordovician age rest on eroded Lower Ordovician and Upper Cambrian rocks in Michigan, northern Indiana, and northwestern Ohio and range in thickness from less than 200 feet in the Northern Peninsula to more than 900 feet in southeastern Michigan. These rocks are thickest a short distance east of the center of the present Michigan basin and are thinner over major anticlinal folds. This indicates that the basin was depressed in an area somewhat similar to its present form as early as Middle Ordovician time.

Oil and gas were commercially produced from the "sub-Trenton" rocks in Ohio on the east flank of the Findlay arch in several small areas. Showings of oil and gas in these rocks have been reported from wells in northeastern Indiana, southeastern Michigan, and southwestern Ontario. The Trenton limestone, which is the producing formation in the Lima-Indiana field, is productive in small areas in southeastern Michigan and southwestern Ontario.

Upper Cambrian and Ordovician rocks occur in the subsurface throughout the Michigan basin and crop out around the margin of the basin in Illinois, Wisconsin, the Northern Peninsula of Michigan, Manitoulin and adjacent islands, and the Bruce Peninsula in Ontario. Middle and Upper Ordovician rocks crop out at places in Ontario eastward to the Frontenac axis (Fig. 1). The thickness of the formations varies in the Michigan basin as a result of regional thinning and thickening and of erosional unconformities. Upper Cambrian sandstones, which may be more than 2,500 feet thick in places, are the oldest deposits on the pre-Cambrian surface.

[1] Manuscript received, February 28, 1948. Published by permission of the director of the United States Geological Survey.

[2] Geologist, United States Geological Survey. Studies of stratigraphic problems in the Michigan basin have been conducted for the past 4 years by the Geological Survey, United States Department of the Interior. These studies have been made as part of its program of oil and gas investigations in coöperation with the Geological Survey Division, Department of Conservation, Lansing, Michigan, and the Department of Geology, University of Michigan, Ann Arbor, Michigan.

For drill cuttings and well records and other assistance in the studies the writer greatly appreciates the assistance of members of the Michigan, Illinois, Wisconsin, Indiana, and Ohio geological surveys; the Geological Survey of Canada; the Department of Geology, University of Michigan; George D. Lindberg, Sun Oil Company, Toledo, Ohio; R. G. Kurtz and George T. Thomas, Ohio Oil Company, Findlay, Ohio; Anthony Folger, consulting geologist, Wichita, Kansas; Charles S. Evans, Union Gas Company, Chatham, Ontario; and B. R. MacKay, Geological Survey of Canada, Ottawa, Canada.

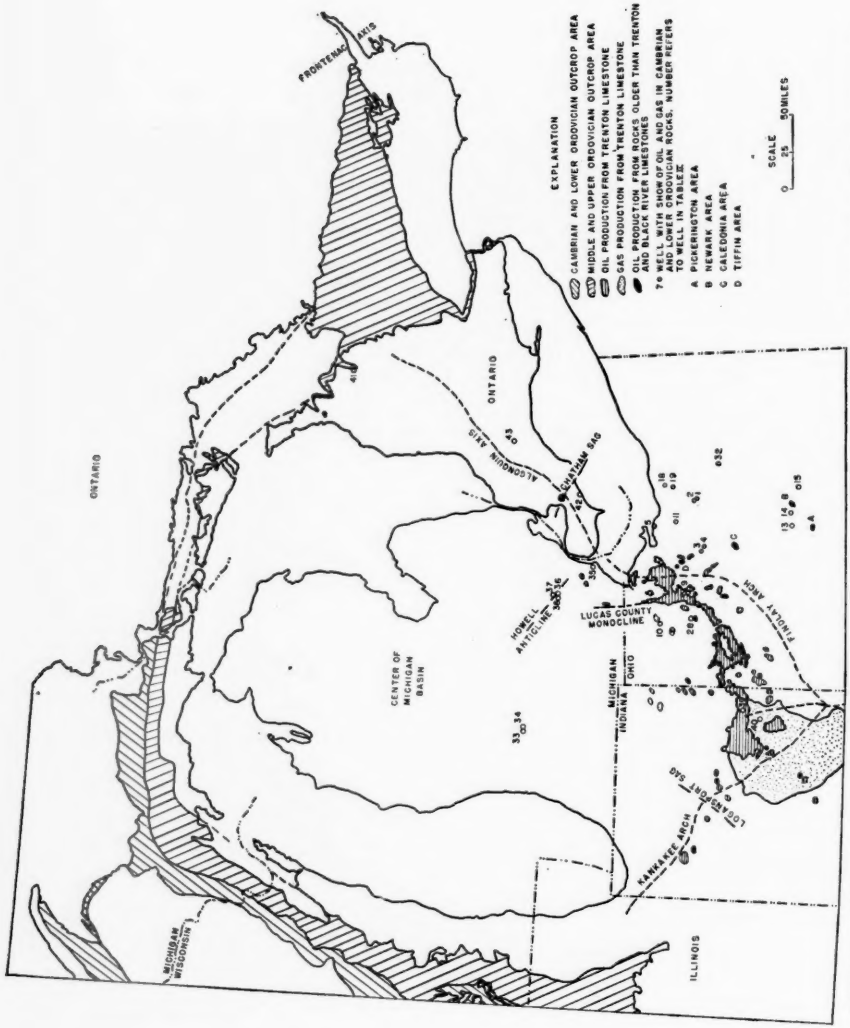


FIGURE 1. OUTCROP AREAS OF CAMBRIAN AND ORDOVICIAN ROCKS, AND MAJOR STRUCTURAL FEATURES AROUND THE MICHIGAN BASIN. AREAS OF OIL AND GAS PRODUCTION FROM THE TRENTON LIMESTONE AND OLDER ROCKS ARE ALSO SHOWN.

...LIMESTONE AND OLDER ROCKS ARE ALSO SHOWN.

PRE-CAMBRIAN ROCKS

Granite and metamorphic rocks have been found at the top of the pre-Cambrian in most of the wells that have been drilled through the sedimentary rocks in the Michigan basin. However, in Clark County, Ohio, on the east side of the Cincinnati arch, 1,228 feet of dark gray to black dolomite and limestone and arkose of pre-Cambrian age was penetrated in the Friend-Mattison well. Dark gray to black dolomite at the top of the pre-Cambrian was also penetrated in the Binegar well in Jay County, northeastern Indiana. As granite was found at the top of the pre-Cambrian in wells drilled a few miles distant from both the Mattison and the Binegar wells, it is probable that these occurrences of pre-Cambrian limestone and dolomite are isolated and of small extent. The greatest thickness of pre-Cambrian rocks penetrated in the Southern Peninsula of Michigan is in the Beck-Sancrant well, Monroe County (Table I), where more than 800 feet of granite has been drilled.

CAMBRIAN ROCKS

Overlying the pre-Cambrian rocks in the Northern Peninsula of Michigan is the red arkosic Jacobsville sandstone. This sandstone is mottled and striped with streaks of red clayey shale and is conglomeratic in the basal part. It has been penetrated by wells in a large area and its thickness may be as much as 1,500 feet in some places. Red arkosic sandstones which may be correlated with the Jacobsville have been drilled in a few wells in the Michigan basin; they overlie the pre-Cambrian rocks. According to Thwaites[3] the Jacobsville sandstone may be Upper Keweenawan in age and possibly non-marine in origin.

The Upper Cambrian Mount Simon sandstone rests on pre-Cambrian rocks where the Jacobsville is absent. The greatest thickness drilled to date in the vicinity of the Michigan basin is in northeastern Illinois, where the Mount Simon is 2,500 feet thick. The sandstone thins eastward from Illinois. It is only 300 feet thick in southeastern Michigan, and is absent in parts of southwestern Ontario. It is medium- to coarse-grained sandstone with subangular to rounded grains. A few thin beds of dolomite and sandy dolomite occur in the upper part of the sandstone.

The Eau Claire sandstone consists of sandstone, shale, and dolomite that is shaly and sandy. The dolomite beds in the Eau Claire may be gray to dark gray, pink, purple and red to brown in color, and the shale also is variously colored. Glauconite is locally abundant in the formation west of the Findlay arch. The Eau Claire is much more sandy in western Michigan, northwestern Indiana, Illinois, and eastern Wisconsin than it is in eastern Michigan, Ohio, and northeastern Indiana. It is also much more sandy northward in Michigan, and is entirely sandstone in the Northern Peninsula. It is approximately 600 feet thick in northeastern Illinois but thins to 250 feet in southeastern Michigan.

The Dresbach sandstone is present in Wisconsin, Illinois, Michigan, and north-

[3] F. T. Thwaites, "Stratigraphic Work in Northern Michigan," *Michigan Acad. Sci.*, Vol. 28 (1943), p. 501.

TABLE I

WELLS, WITH DEPTHS TO TOP OF ORDOVICIAN AND OLDER ROCKS DETERMINED FROM MOUNTED DRILL CUTTINGS AT ANN ARBOR, MICHIGAN (DEPTHS AND ELEVATIONS IN FEET)

County	*Well*	*Location Sec.*	*T.*	*R.*	*Elevation*	*Depth to Top of Upper Ordovician*	*Depth to Top of Middle Ordovician*	*Depth to Base of Middle Ordovician*	*Depth to Top of pre-Cambrian*	*Total Depth*
				MICHIGAN						
Alpena	Teater-Nevins 1	18	32N.	6E.	803	4,600	5,146	5,650		5,665
Antrim	Ohio Oil-Chamberlain 1	14	31N.	8W.	738	5,285	5,755	6,093		6,150
Barry	Sun Oil-Kidder 1	8	3N.	9W.	796	3,844	4,409	4,973		5,013
Bay	Gulf Oil-Bateson 1	2	14N.	4E.	599	8,588	9,400	10,361		10,447
Berrien	Sprenger Bros.-Herwig 1	10	4S.	18W.	667	1,720	2,050	2,485		2,710
Berrien	Shelbow-Van Lente 1	35	4S.	19W.	669	1,590	1,862	2,259		2,571
Berrien	Violette-Warren 1	8	8S.	20W.	647	1,076	1,353			1,472
Berrien	Warman-Warman 1	34	3S.	17W.	664	1,920	2,222			2,505
Calhoun	St. Clair Oil & Gas-Hubbard 1	14	2S.	6W.	964	3,340	3,950	4,564		4,572
Cass	Blair & Miller-Knowlton 1	2	8S.	16W.	855	1,558	1,945			2,029
Cass	Daniels-Clute 1	2	7S.	13W.	928	1,970	2,439			2,696
Chippewa	Barton-Kreetan 1	17	41N.	7E.	673	534	998			1,050
Eaton	Wittnier Oil & Gas-Portland Cement	28	1N.	6W.	864	3,650	4,260			4,405
Ingham	Colvin-Glasser 1	14	3N.	1E.	908		5,743	6,568		6,700
Kalamazoo	Smith-Caldwell 1	32	1S.	12W.	970	2,722	3,168			3,348
Kent	Flannigan-Croff 1	35	7N.	9W.	679	4,748	5,321			5,575
Kent	Producers Committee-Riddering 1	30	7N.	12W.	739	4,036	4,603	5,125		5,222
Kent	Smith Petroleum-Sherk 1	21	5N.	10W.	758	3,990	4,550	5,118		5,200
Lenawee	Voorhees-Gove 1	8	5S.	4E.	834	2,601	3,269	4,060		4,060
Lenawee	Berston-Heath 1	13	7S.	5E.	682	1,280	1,985			2,091
Lenawee	LaDu-Long 2	2	7S.	5E.	708	1,670	2,373	3,122		3,297
Lenawee	Socony-Vacuum-Downing Estate 1	36	5S.	5E.	698	1,788	2,445	3,103		3,435
Lenawee	England-Dunigan 1	7	7S.	1E.	956	2,460	3,110			3,165
Lenawee	Socony-Vacuum-McCarberry 1	36	5S.	5E.	694	1,792	2,445			2,552
Lenawee	Socony-Vacuum-Russell 1	25	5S.	5E.	699	1,755	2,423			2,576
Lenawee	Eckert-Taylor 1	32	8S.	5E.	715	1,486	2,197	2,940	3,865	3,900
Lenawee	Cons. Developers-LaVoy 1	25	6S.	5E.	678	1,673	2,354			2,492
Lenawee	Borton-Borton 2	5	6S.	5E.	715	1,965	2,638			2,815
Livingston	Duck Lake Oil-McPherson Estate 1	35	3N.	4E.	914	4,299	5,008	5,910		5,958
Mackinac	Charles Van Keuren-Hiawatha Club 1	17	44N.	9W.	856	625	1,042	1,290		1,500
Manistee	Ruggles-Rademaker 24	12	21N.	17W.	591	4,610	5,000			5,280
Monroe	A. V. Oil & Gas-Roe 1	19	6S.	6E.	681	1,380	2,060			2,110
Monroe	Jetter-Morrison 1	26	6S.	6E.	677	1,442	2,110			2,233
Monroe	Vanco-Montry 2	30	6S.	6E.	678	1,376	2,052	2,811		2,874

Monroe	Duffey-Putnam and Russell 1	5	6S.	7E.	648	1,550	2,184			2,285
Monroe	Severs-Redway 1	9	7S.	7E.	648	1,265	1,925			2,049
Monroe	Olmsted-Frink 1	25	5S.	6E.	672	1,707	2,325			2,800
Monroe	Berell-Yape 1	7	7S.	6E.	680	1,286	1,985			2,295
Monroe	Sun Oil-Clampitt 1	28	8S.	6E.	690	1,010	1,711	2,486		2,512
Monroe	Sturman-Chapman 1	29	5S.	10E.	597	1,375	2,000	2,914	3,370	3,376
Monroe	Violette-Russell 1	5	6S.	7E.	657	1,550	2,178			2,338
Monroe	Beck-Sancrant 1	19	7S.	7E.	669	1,238	1,948	2,750	3,625	4,452
Monroe	Michigan Pacific Oil & Gas-Wolgamuth 1	6	7S.	6E.	679	1,334	2,028			2,145
Muskegon	Muskegon-Heinz 5	8	10N.	16W.	636	3,820	4,315	4,710		4,754
Oceana	Oceana Petroleum-Vanderwaal 1	33	14N.	17W.	769	4,363	4,755			4,875
Ottawa	Michigan Petroleum-Moe 1	6	9N.	13W.	704	4,526	5,046	5,490		6,310
Ottawa	Miller-Sako 1	27	7N.	16W.	613		3,690			3,839
Sanilac	Shell Oil-Burch 1	15	10N.	15E.	761	4,884	5,514			5,820
St. Clair	St. Clair Oil & Gas-Hurst 1	26	5N.	16E.	620	3,015	3,625	4,590	4,730	4,770
St. Clair	Mueller Brass-Van Antwerp 1	9	6N.	17E.	609	3,300	3,910	4,895		4,948
St. Joseph	Ora Avery-Dunworth 1	13	6S.	11W.	866	2,130	2,594			2,693
Schoolcraft	Manistique-Municipal Deep Well	11	41N.	16W.	600	554	925	1,200		1,398
Schoolcraft	Pattison-Verschure 1	14	42N.	16W.	632	365	725	980		1,050
Schoolcraft	Schoolcraft & Dev. Syndicate 2	31	41N.	13W.	642	605	1,010	1,293		1,710
Van Buren	Wolverine Oil-Vought 3	32	4S.	14W.	772	2,070	2,420			2,523
Van Buren	Michigan-California Oil-Piper 1	36	1S.	16W.	650	2,260				2,587
Washtenaw	Violette-Sanderson 1	26	4S.	7E.	674	1,945	2,545			2,680
Washtenaw	Colvin-Voss 1	16	1S.	7E.	915		4,318	5,210	6,372	6,410
Washtenaw	Colvin-Meinzinger 1	12	2S.	7E.	819	3,205	3,798	4,696	5,670	5,692
Washtenaw	Colvin-Roddenberry 1	27	1S.	7E.	886	3,520	4,105	5,019	6,070	6,085
Wayne	Darke Bros.-Truesdale 1	25	2S.	8E.	658	2,640	3,240			3,600
Wayne	H. R. Ford Well	22	2S.	10E.	612	2,475	3,055	3,940		4,050
Wayne	Colvin-Theison 1	16	4S.	9E.	625		2,445	3,354	4,000	4,050
Wayne	Pontchartrain Petrol.-Baynton 1	27	4S.	8E.	640		2,440			2,566
Wayne	Bonanza Oil-De Roy 1	22	4S.	8E.	642	1,960	2,470			2,568
Wayne	Union Drilling-Angell 1	7	1S.	8E.	922	3,526	4,137			4,288
Wayne	Pennsylvania Salt Well 14	5	4S.	11E.	600	1,910	2,505	3,350		3,368
				OHIO						
Fulton	Stevens *et al.*-Rupp 3	19	7N.	6E.	752	1,365	2,129			2,179
Putnam	Ohio Oil-Barlage 1	29	2N.	7E.	740	626	1,433	2,030	3,345	3,377
Wood	Ward *et al.*-Shaw 1	1	4N.	10E.	685	625	1,315			1,345
Wood	Schwyn-Brailey 8	12	4N.	10E.	685		1,294	1,932	2,908	2,927
Wyandot	Ohio Oil-Chatlin 1	28	3S.	15E.		700	1,750	2,368		2,390
Wyandot	Ohio Oil-Heck 1	18	1S.	13E.	860	350	1,322	1,914		2,801
Ashland	Ohio Oil-Krause 1	14	1N.	20W.	1,104	2,484	3,756	4,414		5,218
Delaware	-Vance 1	3	3N.	18W.	920	995	2,100	2,679	3,845	4,290
Geauga	East Ohio Gas-Crile 1	Lot 1, Tract 4	9N.	8W.	1,031	3,650	5,249	5,924		6,101
Loraine	Ohio Fuel-Lincoln 1		4N.	18W.	810			4,266		4,356
Loraine	Hanley & Bird-Pitts 1	Lot 93	4N.	18W.	830			4,205		4,230

TABLE I—(*continued*)

County	*Well*	*Location Sec.*	*T.*	*R.*	*Elevation*	*Depth to Top of Upper Ordovician*	*Depth to Top of Middle Ordovician*	*Depth to Base of Middle Ordovician*	*Depth to Top of pre-Cambrian*	*Total Depth*
Loraine	Hanley & Bird-Nash 1	Lot 87	4N.	18W.	812			5,202		4,284
Muskingum	Ind. Gas Corp.-Whitmire 1	Lot 26	13N.	12W.				6,610		6,740
Seneca	Wicklund Dev'l.-M. Hammer 1	22	3N.	13E.	760		1,298	2,043		2,043
Seneca	Ohio Oil-Bishop 1	13	2N.	16E.	908	1,032	2,052	2,677		3,123
Seneca	-Hostler 1	3	2N.	14E.		510	1,435			1,560
Wayne	Ohio Oil-Armstrong 8	14	15N.	13W.	1,119	3,625	5,005	5,722		6,116
			INDIANA							
Adams	McKee-Glendenning 1	35	25N.	13E.	845		1,005	1,522		2,460
Benton	Palmer-Atkinson 1	3	25N.	7W.	758	790	1,078			1,154
Cass	Nat'l. Petroleum-Pufahl 1	22	28N.	1W.	732	580	949			1,055
Cass	Eastman-Shaeffer 1	11	28N.	1W.	740	554	932	1,346		1,377
Henry	Ohio Oil-May 1	12	16N.	11E.	1,032		870	1,370	3,648	3,670
Jasper	Kankakee Valley Development-State Bank of Rensselaer 1	14	30N.	6W.		626	943	1,300		3,330
Jasper	National Petroleum-Rose 1	4	29N.	5W.	693	598	889			900
Jasper	National Petroleum-Wortley 1	19	28N.	6W.	673	642	958			1,058
Jay	Petroleum Development-Binegar 1	29	24N.	13E.	948		1,006	1,432		3,404
Jay	Henderson-Ickes 1	35	23N.	15E.	957	235	1,070			1,134
Lake	Superheater-Fee 1	29	37N.	9W.	595	594	765	1,090		1,825
Newton	National Petroleum-Bokma 1	22	27N.	8W.	687	750	1,030			1,070
Noble	Texas Oil-Frank 1	27	35N.	9E.	892	1,415	1,925			2,040
Owen	Sun Oil-Chambers 1	23	10N.	5W.	722	1,970	2,344	2,985		3,180
Perry	Sun Oil-Gibson 1	17	4S.	1W.	735	2,261	2,860	3,365		3,534
Pulaski	Lyons-Ruff 1	24	29N.	2W.	705	584	938			949
St. Joseph	Ohio Oil-Pearse 1	28	36N.	1E.	729	1,080	1,395			1,514
Starke	Tamblyn Dev'l.-Francois 1	5	32N.	2W.	718	775	1,068			1,171
Steuben	Texas Oil-Tuttle 1	27	36N.	13E.	986	1,720	2,325			2,500
Tipton	Eastman-Vandervender 1	21	21N.	3E.			991	1,484		1,527
Wabash	Texas Oil-Schultz 1	24	28N.	6E.	792	500	1,040			1,067
Wayne	Wayne Co. Producing-Taylor 1	22	13N.	1W.	1,028	995		1,490		3,330
Wells	Texas Oil-Aschleman 1	7	27N.	13E.	838	425	1,148			1,170
White	McGuire-Clark 1	35	28N.	4W.		570	898			928
White	Ohio Oil-Matthews 1	11	26N.	6W.	733	615	950			1,060

TABLE I—(*continued*)

ONTARIO, CANADA

County	*Well*	*Location* *Lot*	*Conc.*	*Township*	*Elevation*	*Depth to Top of Upper Ordovician*	*Depth to Top of Middle Ordovician*	*Depth to Base of Middle Ordovician*	*Depth to Top of pre-Cambrian*	*Total Depth*
Brant	Hamblin Stanley-Sharp 1	5	2	Onondaga	695	570	1,980			2,723
Bruce	McKillopp-Hughes 2	14	10	Amabel	603	290	1,055			1,485
Bruce	Rowe-McKenzie 3	18	5	Culross	1,039	1,418	2,164	2,855		2,855
Bruce	Mulberry Creek Oil-Fowlie 1	17	4	Eastnor	592	400	1,030			1,597
Bruce	Imperial Oil & Union Gas-Semple 1	60	A	Kincardine	596	1,598	2,277	2,880		2,923
Elgin	Dominion Natural Gas-Hooley 2	23	10	Dunwich	597	1,640	2,730	3,560		3,580
Elgin	Union Gas 62-White	1	5	Malahide	699	1,496	2,708	3,485		3,536
Essex	Southern Ontario Gas-Cornwall 1	18	1	Colchester South	593	1,400	2,035	2,895		2,905
Essex	Morley & Ferris 15	8	1	Gosfield South	642	1,640	2,375			2,940
Essex	Imperial Oil-Gulliver 1	1	7	Mersea	641		2,520	3,340		3,360
Essex	Union Gas-Imperial Oil 3	14	11	Tilbury North	608	1,842	2,602	3,443	3,528	3,549
Essex	E. Coste-M. J. Keck 1	5	10	Tilbury West	610	1,838	2,572	3,418	3,418	3,423
Grey	McKenzie *et al.*-Binnie 1	180	2W.	Artemesia	1,610	465	1,420	1,940	1,954	1,970
Grey	Blue Mountain Oil & Gas-Reekie 3	26	7	Collingwood	621		85	700	700	747
Grey	Doran Oil & Gas-Doran 4	25	7	St. Vincent	752		390	958		966
Grey	Forest-Hind 1	28	3	Sarawak	720		715	1,297	1,297	1,320
Halton	Rockwood Oil & Gas-Slater 1	12	3	Nasagawaya	1,013	230	1,560	2,220		2,240
Huron	Huron & Bruce Oil-Trewartha 1	23	2	Hullett	980	1,980	2,710	3,480	3,496	3,530
Kent	Union-Imperial 2	4	13	Chatham	581	2,364	3,030	3,886	3,886	3,886
Kent	Union Gas-Chatham 1	1	14	Chatham	585	2,046	2,750	3,667	3,667	3,668
Kent	Union Gas-Chatham 73	2	14	Chatham	584	2,065	2,762	3,696	3,696	3,700
Kent	Central Pipe Line-Antaga 1	1	4	Dover East	580	2,180	2,900			3,309
Kent	Coste 7	17	7	Dover East	582	2,170	2,888	3,780	3,800	3,823
Kent	Prairie Oil & Gas-Thomas 6	5	2	Dover East	581	2,110	2,870			3,274
Kent	Union Gas-English 1	2	4	Harwich	595	2,046	2,872	3,783		3,789
Kent	Union Gas-Crowe 1	6	2	Raleigh	578	2,050	2,805	3,696		3,700
Kent	Dominion Gas 251-Shanks 6	184	NTR	Romney	633	1,907	2,735	3,608		3,654
Lambton	Union Gas 2-Mackie 1	26	6	Dawn	656	2,170	2,920	3,860	3,870	3,939
Lambton	MacIntosh Oil & Gas-MacIntosh 1	14	10	Enniskillen	627	2,446	3,120	4,095		4,124
Manitoulin	Etheridge & Olson Dev'l.-McIvor 2	24	4	Assiginack	750	46	557			790
Manitoulin	Sault Ste. Marie Synd.-Marshall 1	44	1	Assiginack	664	75	445			487
Manitoulin	MacDougall-Graham 1	28	8	Carnarvon	720			1,340	1,355	1,393

TABLE I—(*continued*)

County	*Well*	*Location* *Lot*	*Conc.*	*Township*	*Elevation*	*Depth to Top of Upper Ordovician*	*Depth to Top of Middle Ordovician*	*Depth to Base of Middle Ordovician*	*Depth to Top of pre-Cambrian*	*Total Depth*
Manitoulin	Cockburn Island Synd.-Bay City Bank 1	11	8	Cockburn Island	984	585	990			1,236
Manitoulin	Cockburn Island Synd.-Flood 1	20	13	Cockburn Island	820	350	780			1,170
Manitoulin	Cockburn Island Synd.-McMillan 1	16	12	Cockburn Island	875	395	836			1,175
Manitoulin	Sault Ste. Marie Synd.-McCrea 1	5	11	Gordon	770	30	470			610
Manitoulin	-G. Wright 1	11		Gordon		40	475			545
Manitoulin	-G. Jaggard 1	13	A	Sheguindah		30	530			580
Manitoulin	-Overfell 1	3	8	Tehkumah		320	802			1,157
Middlesex	Union Gas-Lethbridge 1	7	5S.	Ekfrid	678	1,700	2,675	3,534	3,556	3,585
Middlesex	Dominion Petroleum-Walker 1	6	6	Mosa	706	2,020	2,865	3,750	3,750	3,755
Oxford	Beachville well	18	2	Oxford North	893	1,110	2,260			2,790
Peel	A. E. Hoover-Cooksville	15	1	Toronto	575		785	1,380	1,420	1,425
Perth	St. Mary's Cement	21	17	Blanshard	1,015	1,415	2,360	3,152	3,165	3,174
Perth	Volcanic Oil & Gas-Chalmers 1	23	8	No. Easthope	1,280	1,195	2,210	2,970	2,970	2,978
Perth	Mitchell Syndicate-Challenger 1	20	2	Logan		1,380	2,430	3,135	3,135	3,187
Wellington	Bollert Oil & Gas-Neubauer 1	7	4	Puslinch	1,050	448	1,681	2,360	2,360	3,240
Wentworth	Rockston Oil & Gas 3	30	4	Beverly	820	320	1,645	2,330	2,335	2,675
Wentworth	Dundas Valley Oil & Gas-Woodley 1	10	1	West Flamboro	442	220	1,275	2,065	2,100	2,123

western Indiana. It is absent in northeastern Indiana but is present in northwestern Ohio and continues eastward across the Findlay arch. In southeastern Michigan it is approximately 100 feet thick and is coarse sandstone with well rounded grains. Thin beds of dolomite are found in parts of the sandstone.

Overlying the Dresbach sandstone is the Franconia sandstone, which consists of fine, angular grains of quartz. Thin beds of sandy dolomite occur in the sandstone in places. The sandstone is generally very glauconitic. In southeastern Michigan it is 10–20 feet thick, but in northeastern Illinois where it is sandstone and sandy dolomite it attains a thickness of 70 feet in places. In eastern Wisconsin the sandstone is red and pink in some areas and as much as 140 feet thick. The basal part of the Franconia sandstone at many places in Wisconsin consists mainly of reworked sand grains of the Dresbach.

The Trempealeau formation is a distinct lithologic unit consisting predominantly of dolomite, somewhat sandy in parts, but it also includes some shaly dolomite and dolomitic shale at the base. It is 700 feet thick in northern Indiana but thins westward into northeastern Illinois to 400 feet, and thins to 500 feet in southeastern Michigan. The formation is generally sandy at the top and may be sandy at the base in places. Small amounts of chert are found in the Trempealeau. In places a considerable thickness of pink dolomite has been drilled, but this dolomite is a local occurrence, as the samples from near-by wells show no pink dolomite although the thickness of the formation is approximately constant.

The Trempealeau is divided into the St. Lawrence, Lodi, and the Jordan sandstone members in ascending order. The basal part of the St. Lawrence member consists of gray, sandy, very glauconitic dolomite overlain by dark gray to black dolomitic shale and dolomite. The Lodi member is generally white to buff dolomite, slightly sandy. Pink dolomite occurs locally in this member in southeastern Michigan. The Jordan sandstone member is not present in southeastern Michigan and northwestern Ohio; it may be represented by sandy dolomite in northern Indiana. The sandstone is present in the Northern Peninsula where it is 5–30 feet thick and consists of well rounded, frosted, and pitted quartz grains.

In the Northern Peninsula of Michigan the term Lake Superior sandstone was given to the sandstone exposed along the south shore of Lake Superior by Houghton.[4] Seaman[5] proposed the name Jacobsville for that part of the Lake Superior sandstone skirting the coast at intervals from a point east of Copper Range to Grand Island and proposed the name Munising for the upper 250 feet of white or red, southward-dipping, Lake Superior sandstone which crosses the bluff back of Munising. The Munising sandstone is believed to be equivalent to the lower part of the Trempealeau, the Franconia, Dresbach, Eau Claire, and Mount Simon sandstones. Parts of the Munising sandstone are red in color but

[4] Douglas Houghton, "3rd Ann. Rept. of the State Geologists of the State of Michigan for 1839," *Michigan House of Reps.* (Doc.), No. 8 (1940), p. 13.

[5] A. C. Lane and A. E. Seaman, "The Geological Section of Michigan," *Jour. Geol.*, Vol. 15 (1907), p. 692.

can be easily differentiated from the underlying red arkosic Jacobsville sandstone.

The Hermansville limestone, named by Van Hise and Bayley,[6] includes dolomite and sandstone of both Lower Ordovician and Upper Cambrian age which can be traced in subsurface studies into northeastern Wisconsin. Thwaites[7] states that the Hermansville apparently includes equivalents of both the Trempealeau and Prairie du Chien formations. Subsurface studies show that the Oneota dolomite of Lower Ordovician age overlies the Jordan sandstone member of the Trempealeau in the Northern Peninsula and constitutes the upper part of the Hermansville.

LOWER ORDOVICIAN ROCKS

The Oneota dolomite consists of buff to brown dolomite and contains small amounts of green shale in places. It is very cherty and sandy in parts and oölitic chert is common. The Oneota is present in northern Illinois, Indiana, and western Michigan, but is absent in southeastern Michigan and northwestern Ohio. Wells in southwestern Michigan have penetrated approximately 300 feet of the Oneota; it is largely sandstone with subordinate amounts of dolomite and chert.

The New Richmond sandstone is a thin sandstone unit overlying the Oneota dolomite and underlying the Shakopee dolomite. It is recognized in wells in northern Illinois and Wisconsin, southwestern Michigan, and northeastern Indiana where it is 5–10 feet thick.

The term Shakopee dolomite is used for beds overlying the New Richmond sandstone and underlying the St. Peter sandstone. The Shakopee is found in wells in southwestern Michigan and northwestern Indiana and consists of buff, brown, and gray dolomite with thin beds of shale and a small amount of chert. It may also be sandy in part. Approximately 100 feet of the Shakopee dolomite was drilled in the Sun Oil Company's Mead No. 1, Barry County, Michigan. In the Moe well in Ottawa County it is 120 feet thick and consists of sandstone, gray and dark shaly dolomite, and dolomitic shales. The Shakopee is absent in part of southwestern Michigan and in much of the area in northern Illinois and northwestern Indiana along the Kankakee arch. Its absence in these areas is due to uplift and erosion in pre-St. Peter time.

The St. Peter sandstone of Lower Ordovician age is present in Wisconsin, Illinois, western Indiana, and western Michigan. Although it is generally absent in eastern Michigan and the Northern Peninsula of Michigan, eastern Indiana, and northwestern Ohio, some wells have penetrated a thin sandstone underlying Middle Ordovician rocks which probably is the time equivalent of the St. Peter. The sandstone unconformably overlies Lower Ordovician and Cambrian strata in parts of northern Illinois and Wisconsin and unconformably overlies Lower Ordovician beds in northwestern Indiana and southwestern Michigan. Powers[8]

[6] C. R. Van Hise and W. S. Bayley, "Menominee, Michigan," *U. S. Geol. Survey Geol. Atlas Folio 62* (1900).

[7] F. T. Thwaites, *op. cit.*, p. 501.

[8] E. H. Powers, "Isopach Map of the Prairie du Chien Group," *Rept. 9th Ann. Field Conf., Kansas Geol. Soc.* (1935), p. 350.

states that the Prairie du Chien was evidently eroded to a surface of high relief and completely removed in a large area by a drainage system which apparently opened toward the northeast. Thwaites[9] shows the sandstone to be absent in some parts of Wisconsin. It is approximately 300 feet thick in some areas but absent at localities less than 3 miles distant. Similar local variations in thickness in northeastern Illinois have been found by Lamar[10] and Du Bois.[11]

Cambrian and Lower Ordovician ("sub-Trenton") rocks in Michigan range in thickness from less than 500 feet to more than 3,500 feet (Fig. 2). The aggregate thickness of these rocks increases southwestward from Michigan toward Illinois and decreases southeastward over the Findlay arch in southeastern Michigan and northwestern Ohio (Fig. 3). These rocks increase in thickness eastward into the Appalachian basin (Fig. 4).

MIDDLE ORDOVICIAN ROCKS

At its type locality in Glenwood Township, Winneshiek County, Iowa, the Glenwood consists of shale, which is underlain by St. Peter sandstone. In eastern Wisconsin, northeastern Illinois, southwestern Michigan, and northwestern Indiana, the Glenwood consists principally of fine-grained sandstone and shaly dolomite and ranges from 10 to more than 100 feet in thickness. In southeastern Michigan, northeastern Indiana, and Ohio where the St. Peter sandstone is absent, shale has been found in wells below the Black River limestone. This shale is sandy, green, brown, or gray and in places pyritic. It is 5–30 feet or more thick. In places quartz grains are abundant in the shale, particularly at the contact with the underlying dolomite. The quartz grains were probably derived from the eroded surface of older formations and were concentrated in certain areas. The lithologic character of these rocks is very similar to that of the Glenwood formation although it may not be the exact time equivalent of the Glenwood farther west.[12]

Trenton and Black River rocks are exposed on the north tip of Manitoulin Island and the adjacent St. Joseph and Neebish islands in the north channel at the north end of Lake Huron. In the Northern Peninsula west from Neebish Island, outcrops are almost lacking through Chippewa and Luce counties and eastern Schoolcraft County. However, in Delta County the Escanaba, Rapid, and White Fish rivers provide excellent exposures. There is an outlier of Trenton and Black River rocks at Limestone Mountain, T. 51 N., R. 35 W., Houghton County, Michigan.[13] From west to east across the Northern Peninsula Black

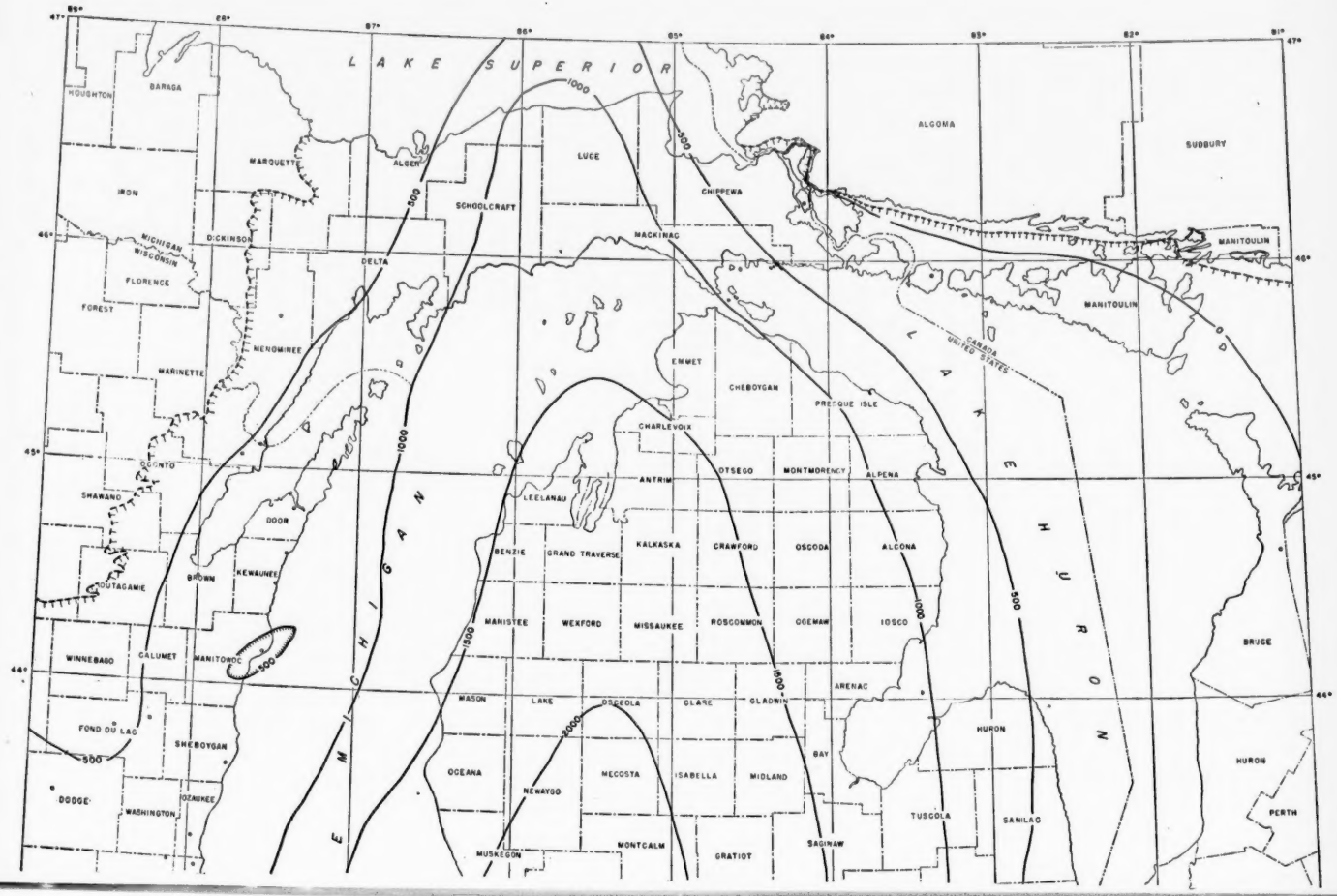
[9] F. T. Thwaites, personal communication.

[10] J. E. Lamar, "Isopach Map of St. Peter Formation," *Rept. 9th Ann. Field Conf., Kansas Geol. Soc.* (1935), Fig. 23.

[11] E. P. DuBois, personal communication.

[12] E. P. DuBois, personal communication.

[13] R. C. Hussey, "The Trenton and Black River Rocks of Michigan," *Michigan Geol. Survey Pub. 40* (1936), Geol. Ser. 34, pp. 233–57.


LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
HOUGHTON
BARAGA
MARQUETTE
ALGER
LUCE
CHIPPEWA
ALGOMA
SUDBURY
IRON
SCHOOLCRAFT
MACKINAC
MANITOULIN
MICHIGAN
WISCONSIN
DICKINSON
DELTA
FLORENCE
FOREST
MENOMINEE
MARINETTE
CANADA
UNITED STATES
EMMET
CHEBOYGAN
PRESQUE ISLE
CHARLEVOIX
OCONTO
ANTRIM
OTSEGO
MONTMORENCY
ALPENA
SHAWANO
LEELANAU
DOOR
BENZIE
GRAND TRAVERSE
KALKASKA
CRAWFORD
OSCODA
ALCONA
OUTAGAMIE
BROWN
KEWAUNEE
MANISTEE
WEXFORD
MISSAUKEE
ROSCOMMON
OGEMAW
IOSCO
BRUCE
WINNEBAGO
CALUMET
MANITOWOC
MASON
LAKE
OSCEOLA
CLARE
GLADWIN
ARENAC
FOND DU LAC
SHEBOYGAN
OCEANA
NEWAYGO
MECOSTA
ISABELLA
MIDLAND
BAY
HURON
DODGE
OZAUKEE
WASHINGTON
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SANILAC
PERTH
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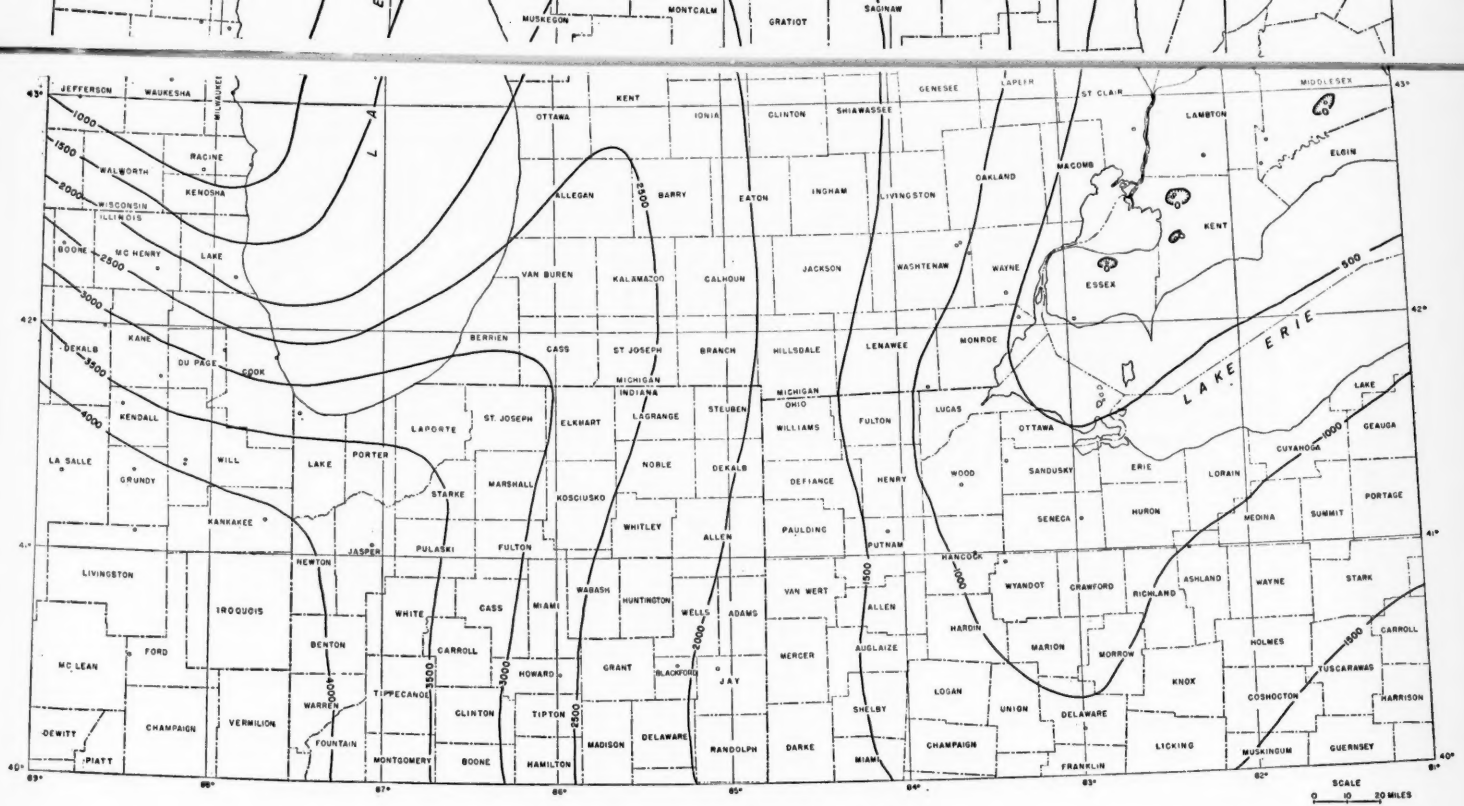


FIGURE 2. THICKNESS OF UPPER CAMBRIAN AND LOWER ORDOVICIAN ROCKS IN THE MICHIGAN BASIN

THICKNESS INTERVAL 500 FEET

BOUNDARY OF UPPER CAMBRIAN AND LOWER ORDOVICIAN ROCKS AT SURFACE

• CONTROL POINT

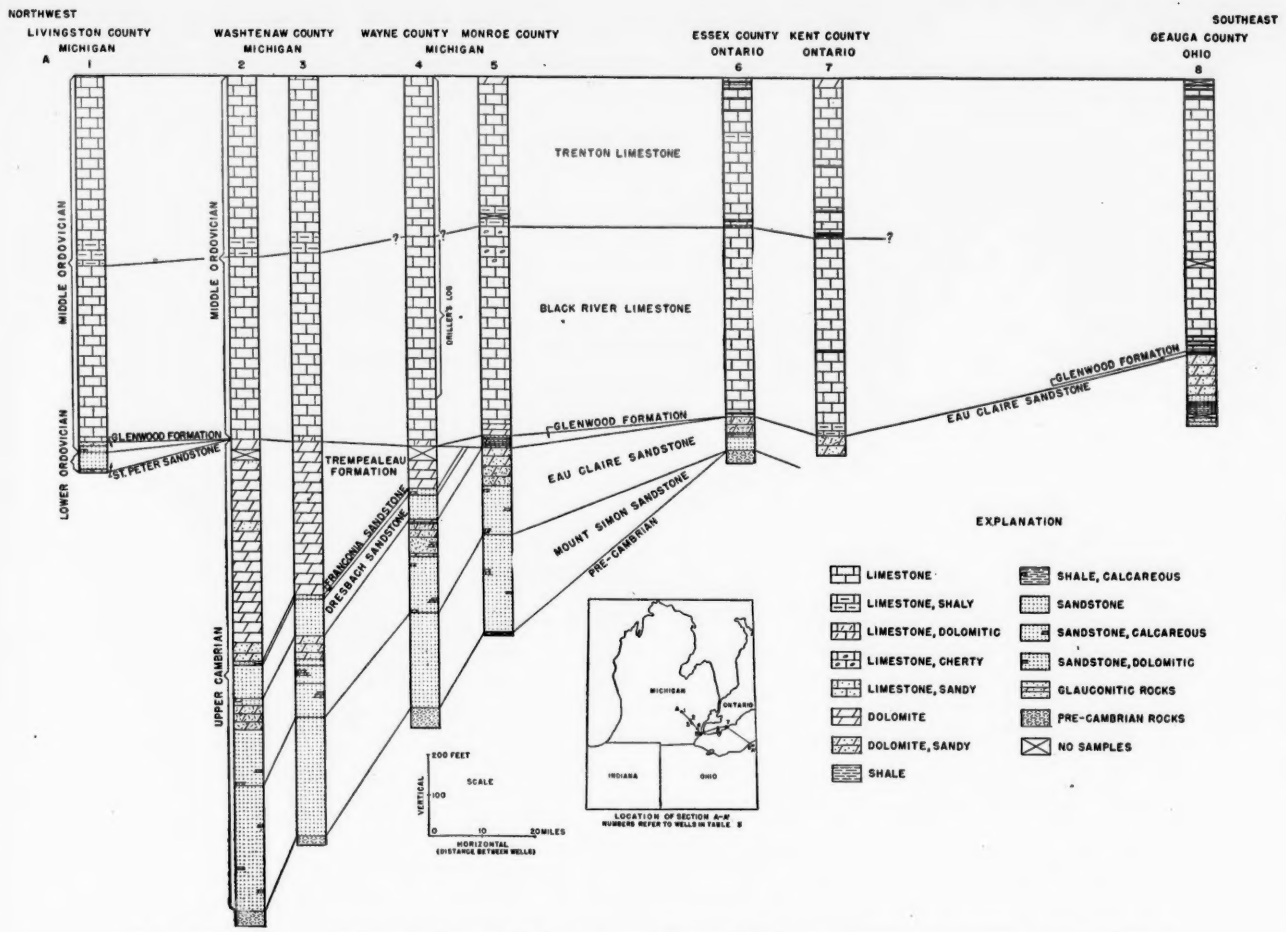


FIG. 3.—Subsurface section from southeastern Michigan to northeastern Ohio showing lithologic characteristics and thickness of Cambrian, Lower and Middle Ordovician rocks.

FIG. 3.—Subsurface section from southeastern Michigan to northeastern Ohio showing lithologic characteristics and thickness of Cambrian, Lower and Middle Ordovician rocks.

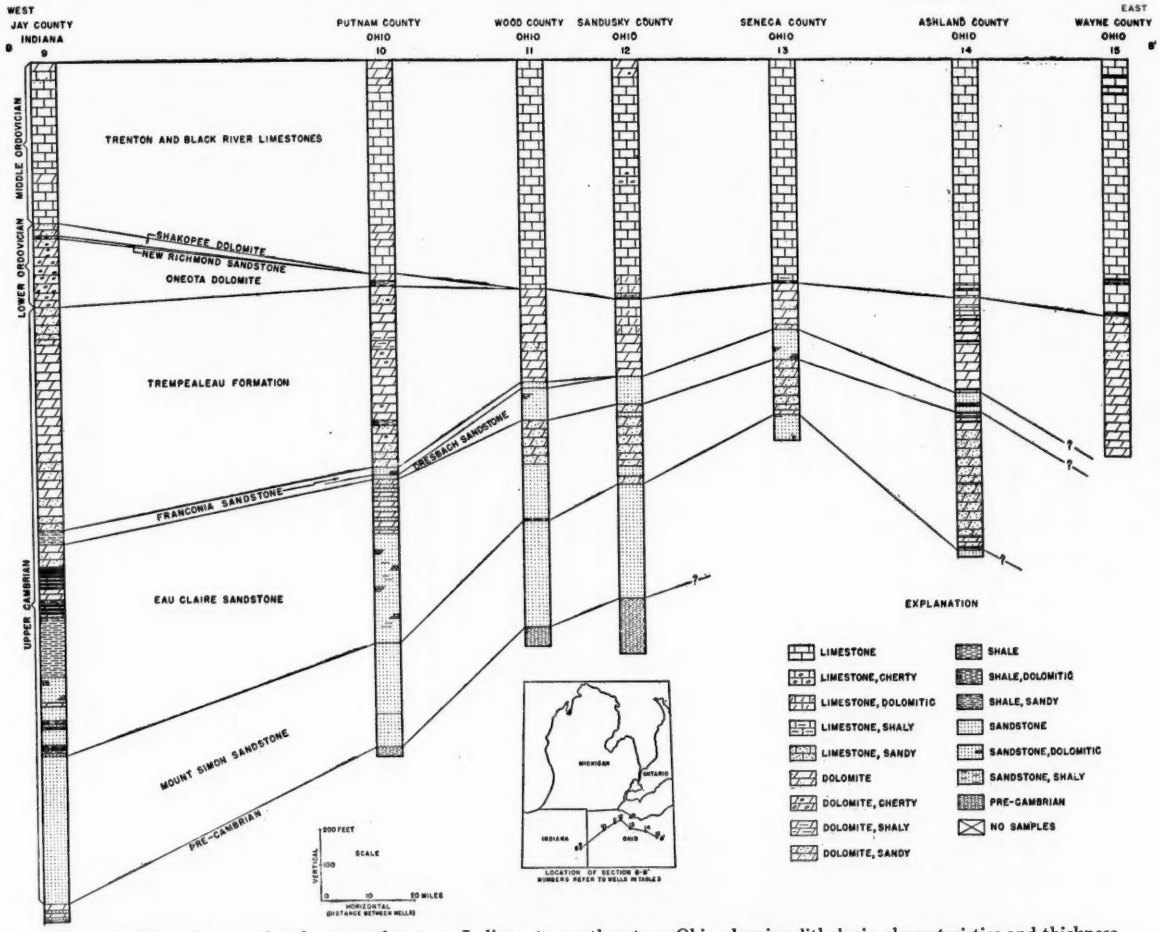


FIG. 4.—Subsurface section from northeastern Indiana to northeastern Ohio showing lithologic characteristics and thickness of Cambrian, Lower and Middle Ordovician rocks.

River strata overlap Lower Ordovician, Cambrian, and pre-Cambrian rocks. A similar overlap occurs along the southern margin of the Michigan basin from southeastern Michigan to Ontario.

The Trenton and Black River rocks generally consist of brown and gray crystalline limestone and dolomite which occur in different proportions in different areas. These rocks are entirely dolomite in eastern Wisconsin, northeastern Illinois, and northwestern Indiana. Along the Kankakee and Findlay arches and around the margin of the Michigan basin they are dolomite and limestone (Fig. 5). In much of the central part of the Michigan basin these rocks are all limestone. The rocks are entirely limestone east of the Findlay arch in eastern Ohio and west of the LaSalle anticline in Illinois. The occurrence of dolomite and limestone along the major anticlinal axes indicates a secondary origin for the dolomite with dolomitization in part related to folding. Oil and gas production and showings in the Trenton limestone are almost entirely limited to the area where the Trenton-Black River sequence is dolomite and limestone or entirely dolomite.

The Black River limestone in the Southern Peninsula is 150–517 feet thick and consists of light brown and gray, fossiliferous, dense to crystalline limestone and dolomite in some places. The uppermost beds here included in the Black River are believed by Kay[14] to be Rockland (Trenton) in age. The basal part of the Black River limestone may consist of fine-grained dark gray to black argillaceous limestone or of limestone and shale. Some chert fragments have been found in the top of the Black River in local areas. In the Northern Peninsula the Black River limestone is 67–86 feet thick and consists of buff to brown, fine-grained, crystalline limestone and dolomite with small amounts of gray argillaceous limestone.

The base of the Trenton limestone has been determined in southwestern Ontario as at the base of very argillaceous limestone and shale sections about 400 feet below the top of the Trenton limestone. The shale and argillaceous limestone is a lithologic unit which can be readily recognized in the subsurface. From southwestern Ontario the Trenton-Black River boundary can be traced into Michigan and can be determined with little difficulty westward across the state except in Berrien County, where the Trenton and Black River rocks are largely dolomite. In the Southern Peninsula of Michigan the Trenton limestone is 203–479 feet thick and its lithologic character is similar to that of the Black River limestone. In the Northern Peninsula the Trenton is 175–206 feet thick and consists of buff to brown crystalline limestone with some dolomite and gray to dark gray argillaceous limestone. The limestone is more argillaceous in the western part of the Northern Peninsula that in the eastern part.

The Trenton and Black River rocks are thickest in eastern Michigan and in the adjoining part of Ontario where they attain a maximum thickness of 985 feet (Fig. 6). Apparently the Michigan basin subsided during Middle Ordovician time at a rate sufficient to permit this thickness of rocks to be deposited. Their re-

[14] G. M. Kay, personal communication.

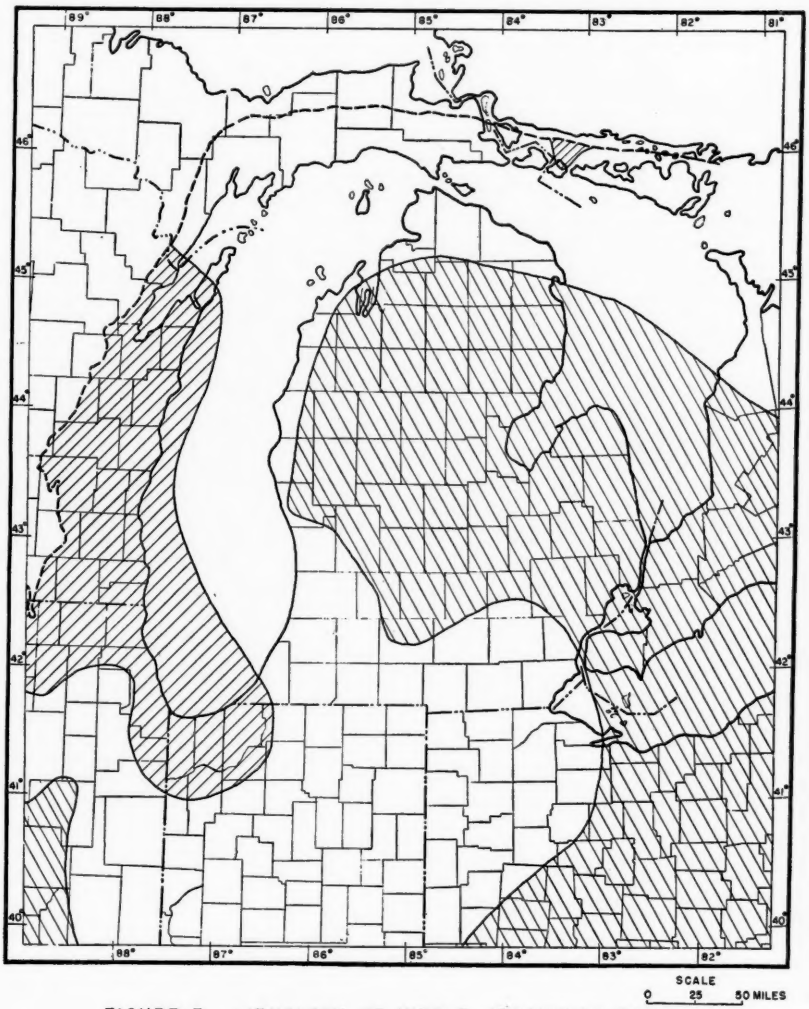
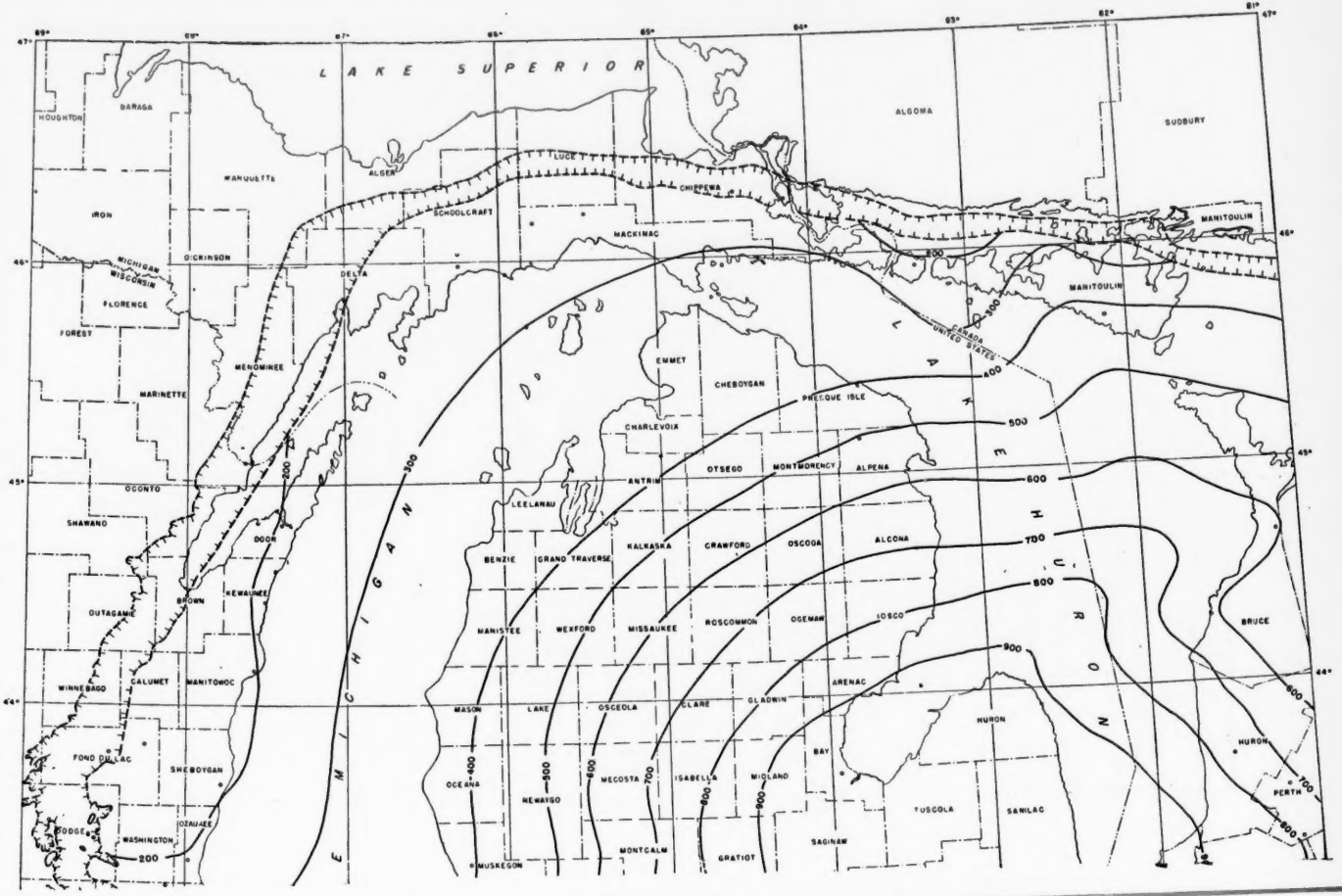


FIGURE 5 LITHOLOGY OF MIDDLE ORDOVICIAN ROCKS


LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
HOUGHTON
BARAGA
MARQUETTE
ALGER
LUCE
CHIPPEWA
ALGOMA
SUDBURY
MANITOULIN
IRON
SCHOOLCRAFT
MACKINAC
DICKINSON
DELTA
MICHIGAN
WISCONSIN
FLORENCE
FOREST
MENOMINEE
MARINETTE
OCONTO
SHAWANO
DOOR
KEWAUNEE
BROWN
OUTAGAMIE
CALUMET
MANITOWOC
WINNEBAGO
FOND DU LAC
SHEBOYGAN
DODGE
WASHINGTON
OZAUKEE
EMMET
CHEBOYGAN
PRESQUE ISLE
CHARLEVOIX
OTSEGO
MONTMORENCY
ALPENA
ANTRIM
LEELANAU
BENZIE
GRAND TRAVERSE
KALKASKA
CRAWFORD
OSCODA
ALCONA
MANISTEE
WEXFORD
MISSAUKEE
ROSCOMMON
OGEMAW
IOSCO
BRUCE
MASON
LAKE
OSCEOLA
CLARE
GLADWIN
ARENAC
HURON
OCEANA
NEWAYGO
MECOSTA
ISABELLA
MIDLAND
BAY
TUSCOLA
SANILAC
SAGINAW
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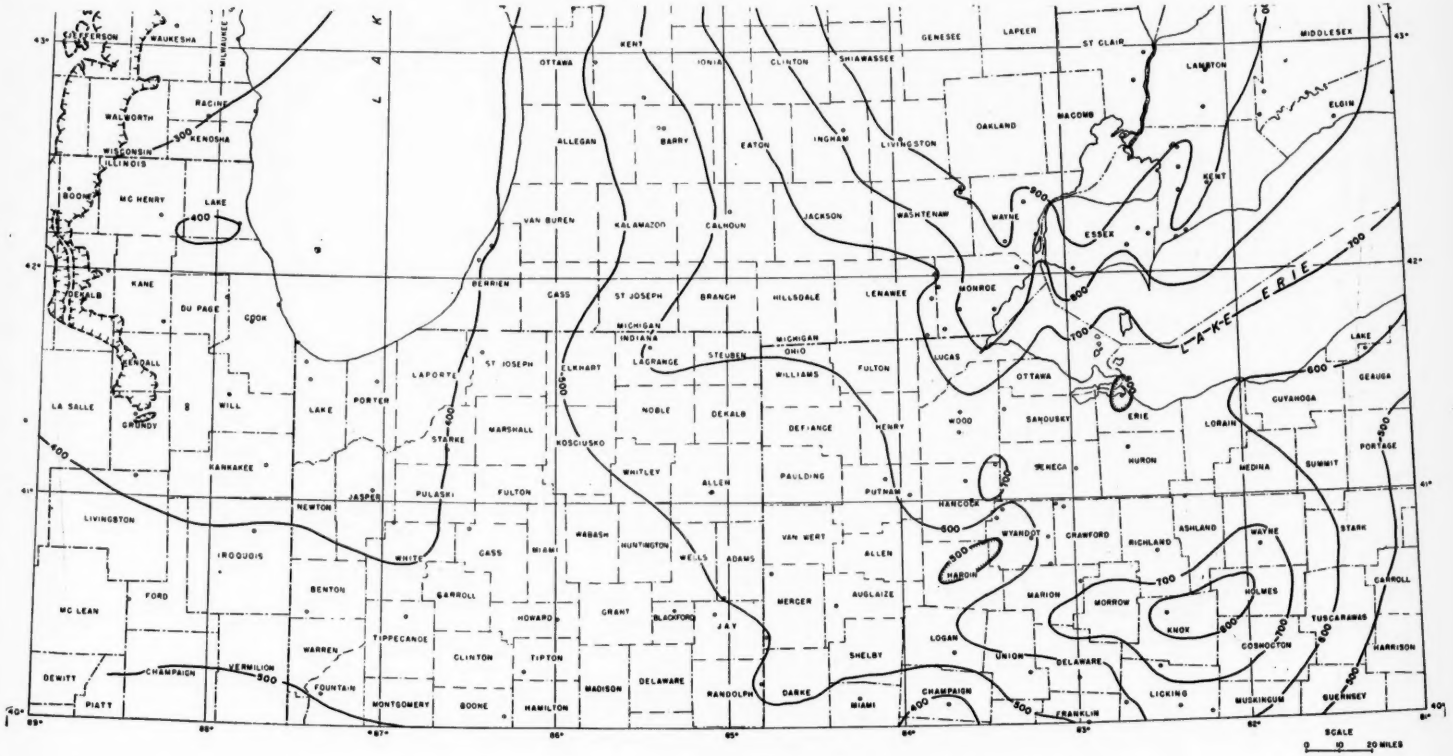
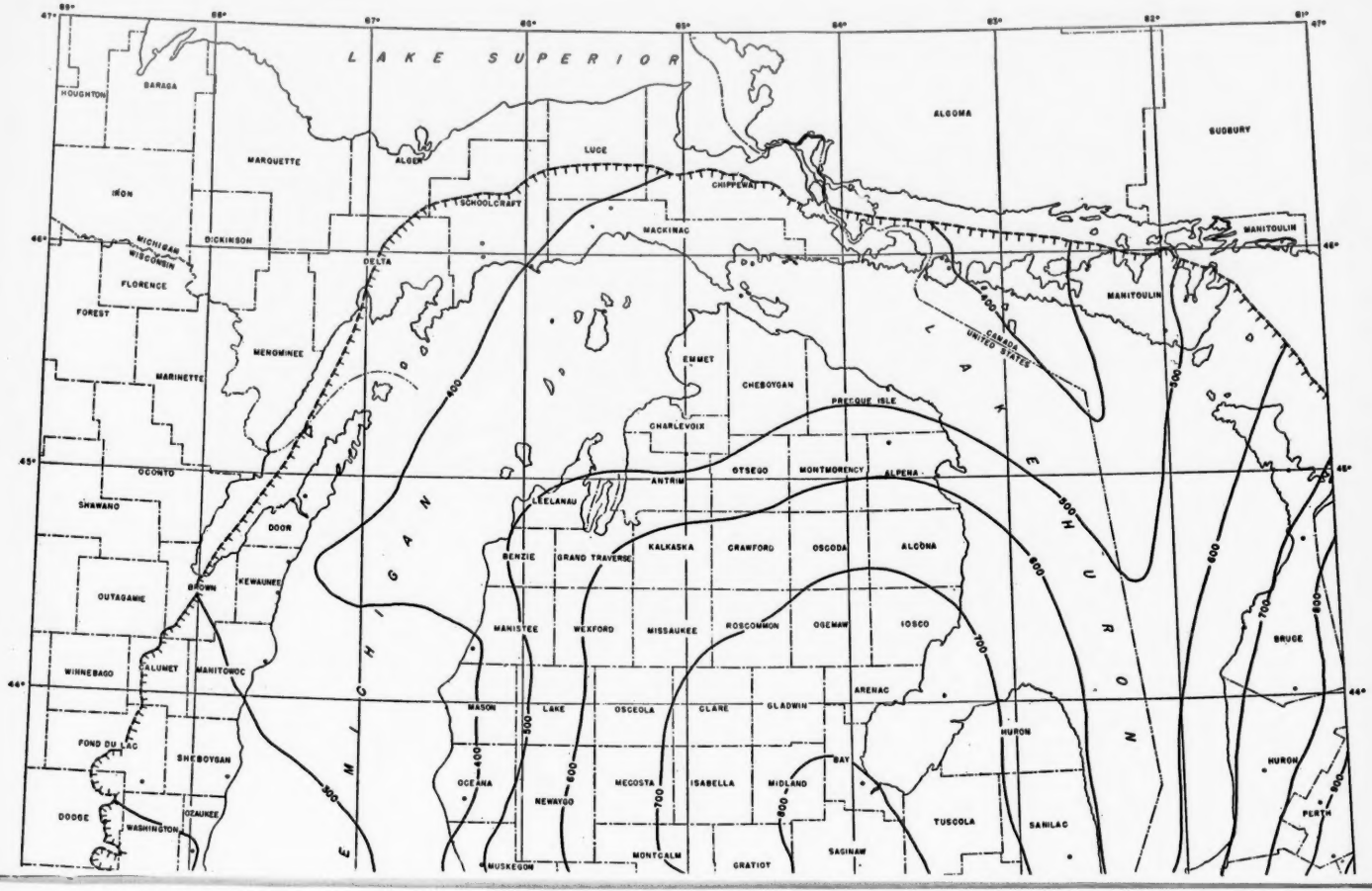


FIGURE 6 THICKNESS OF MIDDLE ORDOVICIAN ROCKS IN THE MICHIGAN BASIN

THICKNESS INTERVAL 100 FEET

OUTCROP AREA OF MIDDLE ORDOVICIAN ROCKS

CONTROL POINT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LUCE
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CHIPPEWA
ALGOMA
SUDBURY
IRON
DICKINSON
MICHIGAN
WISCONSIN
MACKINAC
MANITOULIN
DELTA
FLORENCE
FOREST
MENOMINEE
MARINETTE
EMMET
CHEBOYGAN
PRESQUE ISLE
CANADA
UNITED STATES
CHARLEVOIX
OCONTO
ANTRIM
OTSEGO
MONTMORENCY
ALPENA
SHAWANO
LEELANAU
DOOR
BENZIE
GRAND TRAVERSE
KALKASKA
CRAWFORD
OSCODA
ALCONA
OUTAGAMIE
BROWN
KEWAUNEE
MANISTEE
WEXFORD
MISSAUKEE
ROSCOMMON
OGEMAW
IOSCO
BRUCE
WINNEBAGO
CALUMET
MANITOWOC
ARENAC
MASON
LAKE
OSCEOLA
CLARE
GLADWIN
HURON
FOND DU LAC
SHEBOYGAN
BAY
OCEANA
NEWAYGO
MECOSTA
ISABELLA
MIDLAND
DODGE
OZAUKEE
WASHINGTON
TUSCOLA
SANILAC
PERTH
MUSKEGON
MONTCALM
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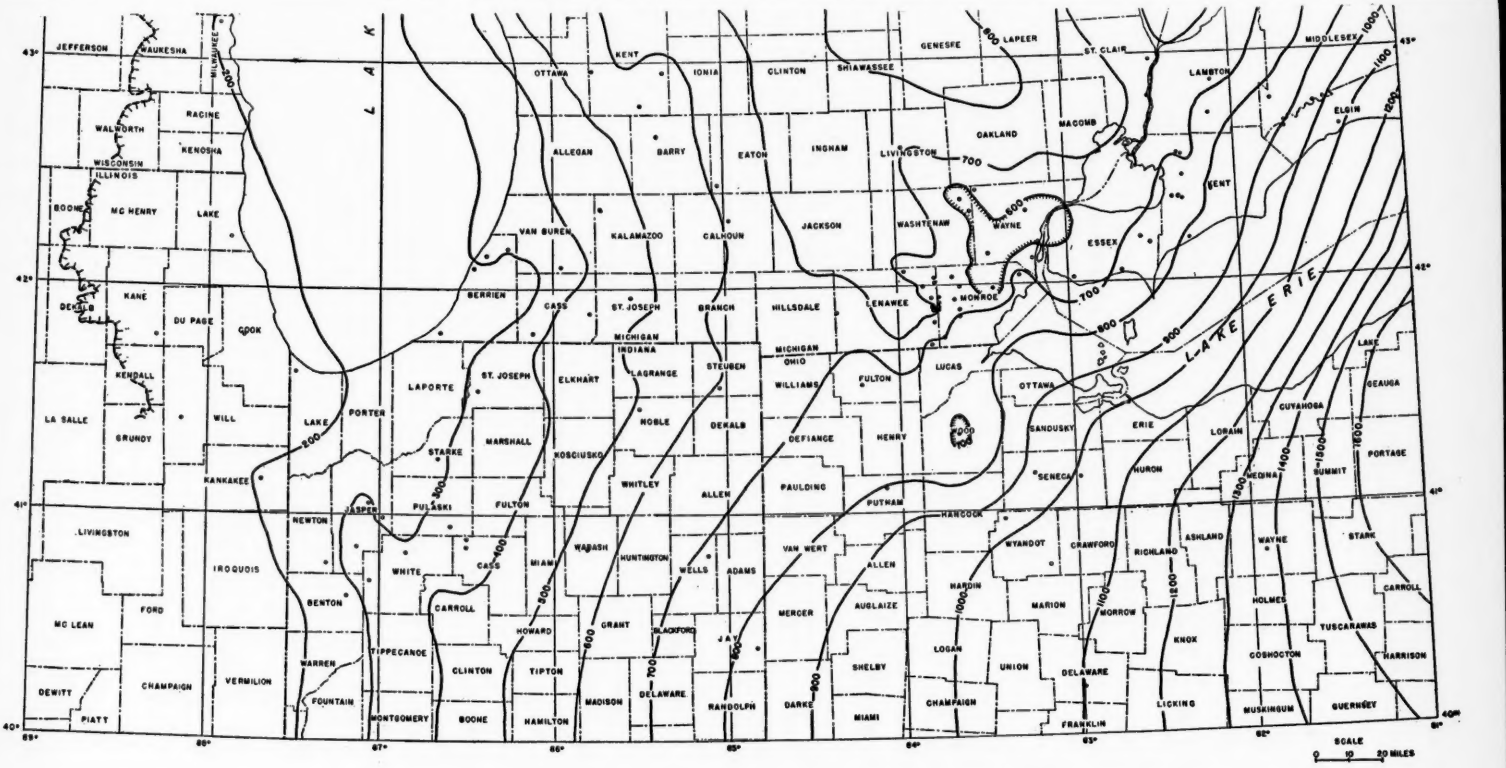

FIGURE 7 THICKNESS OF UPPER ORDOVICIAN ROCKS IN THE MICHIGAN BASIN

THICKNESS INTERVAL 100 FEET

BOUNDARY OF UPPER ORDOVICIAN ROCKS AT SURFACE

• CONTROL POINT

gional thickening in the Chatham sag in Kent County, Ontario, suggests that this was a structurally low area which served as the first connection between the Michigan basin and the seas on the east in Black River time. The Trenton and Black River rocks thin over the Kankakee arch through northern Indiana and they thin slightly at the northern end of the Findlay arch in Essex County, Ontario. There is some thinning on the Cincinnati arch.

UPPER ORDOVICIAN ROCKS

Upper Ordovician rocks in the Michigan basin attain a maximum thickness of 800 feet in the southeastern part of the state near the area of thickest Middle Ordovician rocks. The thickness of these rocks increases greatly eastward into the Appalachian basin (Fig. 7). Some thinning occurs along the Findlay arch and along an area in the vicinity of Lake Huron. The strata are largely gray and dark gray shale with minor amounts of dolomite and limestone. In southeastern Michigan, Upper Ordovician rocks can be divided into the Utica, Lorraine, and Queenston shales in ascending order, but westward across Michigan this subdivision is more difficult to establish due to lateral variation. The Utica shale is dark gray to black and is 150–200 feet thick in southeastern Michigan. The Lorraine shale consists of gray to dark gray, calcareous shale and thin beds of limestone or dolomite in southeastern Michigan and is 290–390 feet thick. The Queenston shale, which is predominantly red shale east of the Michigan basin, is light gray to gray shale with some red shale and interbedded limestone or dolomite in southeastern Michigan where it is 110–200 feet thick. Westward in Michigan the red shale grades into gray shale. Limestone and dolomite are common in the upper part of the Upper Ordovician rocks in western Michigan and in the Northern Peninsula. Upper Ordovician rocks cropping out in the Northern Peninsula are correlated with the Richmond.

STRUCTURE

The Michigan basin is bounded on the west by the Wisconsin arch extending northwest and southeast from central Wisconsin into northern Illinois, and on the southwest by the Kankakee arch which extends from northeastern Illinois to eastern Indiana where it joins the Cincinnati arch. According to Ekblaw[15] the major movement of the Wisconsin arch occurred in post-Cambrian time with less movement possibly occurring during Cambrian time. The first major movement of the Kankakee arch was after Shakopee time but before St. Peter time.[16]

The Wisconsin arch was apparently elevated at various times in Upper Cambrian and possibly Lower Ordovician time, as suggested by the predominance of sandstone in deposits of these ages in eastern Wisconsin. The amount of dolomite in these rocks increases southward and eastward from Wisconsin. The Eau Claire, Trempealeau, and Prairie du Chien rocks contain much sandstone on the west side of Michigan but are less sandy on the east.

The Findlay arch was apparently elevated during Upper Cambrian time as

[15] G. E. Ekblaw, personal communication.

[16] G. E. Ekblaw, "Kankakee Arch in Illinois," *Bull. Geol. Soc. America*, Vol. 49 (1938), p. 1428.

suggested by the thinning of the Mount Simon sandstone eastward from Illinois and over the arch. Major uplift at the close of Lower Ordovician time is indicated by the erosion of Lower Ordovician and Upper Cambrian rocks along parts of the arch in northwestern Ohio and by the absence of all Cambrian and Lower Ordovician rocks on the arch in parts of Ontario. A drop by faulting of more than 200 feet in the top of the Trenton limestone is indicated between well locations in the vicinity of Findlay, Cygnet, and Bowling Green, Ohio.[17] The fault, which is downthrown on the west, extends northward and connects with the Lucas County (Ohio)-Monroe County (Michigan) monocline (Fig. 1).

A structurally low area in Kent County, Ontario, referred to by Kay[18] as the Chatham sag was depressed at frequent times during the Paleozoic era as indicated by the increased thickness of certain Paleozoic rocks in that area. This sag probably served as a connection between the Michigan and Appalachian basins at various times. Likewise, the Logansport sag on the Kankakee arch near Logansport, Cass County, Indiana, was probably a structurally low area connecting the Michigan and Illinois basins at times. The structure of the rocks in the area of the Logansport sag has been discussed by Phinney,[19] Logan,[20] Cummings and Shrock.[21]

The structure of the Michigan basin is complicated with trends of folding developed during several periods of deformation. Structure maps prepared from subsurface data from wells drilled to Devonian and Mississippian formations show dominant northwest-southeast structural trends in the central basin area. In southwestern Michigan the structural alignment is also northwest-southeast but some of the anticlines are aligned northeast-southwest and north-south. The Howell anticline, which is the major structural feature in the Southern Peninsula, extends northwest-southeast through Shiawassee, Livingston, Oakland, Washtenaw, and Wayne counties (Fig. 1). Faulting on the west flank of the anticline is indicated by a well which penetrates the fault plane; in it about 75 feet of Middle Devonian rocks are absent. The contour maps on the tops of different Devonian and Mississippian strata show that the structure of the older rocks conforms to that of the younger rocks. Both Newcombe[22] and Pirtle[23] considered that the

[17] Wilber Stout, "Dolomite and Limestone of Western Ohio," *Ohio Geol. Survey Bull. 42* (1941), 4th Ser., p. 17.

[18] G. M. Kay, "Development of Northern Allegheny Synclinorium and Adjoining Regions," *Bull. Geol. Soc. America*, Vol. 53 (1942), p. 1621.

[19] A. J. Phinney, "The Natural Gas Field of Indiana," *U. S. Geol. Survey 11th Ann. Rept.* (1891), p. 647.

[20] W. N. Logan, *Structural Map of Indiana*, in "Handbook of Indiana Geology," *Indiana Dept. Cons., Div. Geology Pub. 21* (1922), p. 830.

[21] E. R. Cummings and R. R. Shrock, "The Geology of the Silurian Rocks of Northern Indiana," *ibid., Pub. 75* (1928), p. 137.

[22] R. B. Newcombe, "Oil and Gas Fields of Michigan," *Michigan Geol. Survey Pub. 38* (1933), Geol. Ser. 32, pp. 101–26.

[23] G. W. Pirtle, "Michigan Structural Basin and Its Relationship to Surrounding Areas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 2 (1932), p. 151.

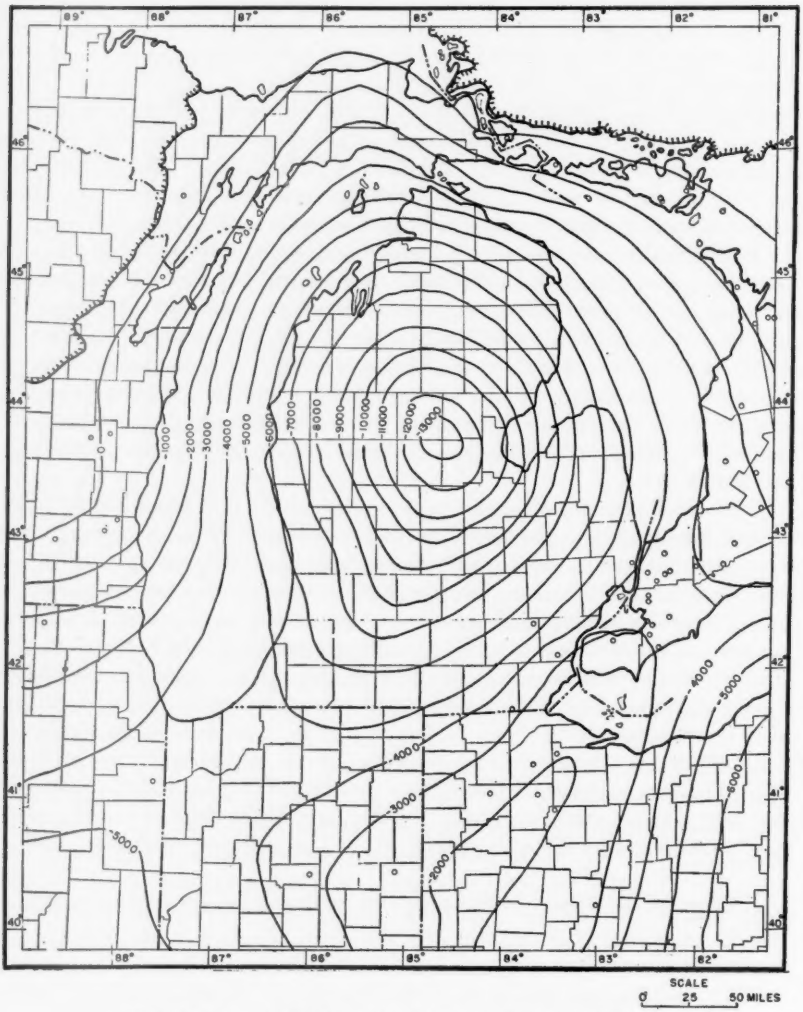

FIGURE 8. CONTOURS ON TOP OF PRE-CAMBRIAN

DATUM, SEA LEVEL

CONTOUR INTERVAL 1000 FEET

BOUNDARY OF PRE-CAMBRIAN AT SURFACE

CONTROL POINT

Michigan basin originated in pre-Cambrian time. Important deformation in the basin occurred in late Mississippian time and additional movement probably occurred in late or post-Pennsylvanian time. The top of the pre-Cambrian is estimated to lie at a depth of approximately 14,000 feet in the center of the Michigan basin in southeastern Clare and southwestern Gladwin counties (Fig. 8).

Little is known about the northern extension of the Michigan basin. A well at Grand Marais in northeastern Alger County penetrated 1,100 feet of sandstone, which suggests that the basin continues as a narrow trough into Lake Superior and is bordered by pre-Cambrian crystalline and metamorphic rocks. It is possible, however, that a pre-Cambrian range, built by folding and continuous with the metamorphic rocks in the western part of the Northern Peninsula, extends eastward under the Paleozoic sedimentary rocks.

The structure of the top of the Trenton limestone shows an estimated relief of 11,000 feet from the outcrops in the Northern Peninsula of Michigan to the center of the Michigan basin (Fig. 9). The top of the Trenton limestone is at sea-level along the Kankakee arch in eastern Indiana and at the southern end of the Findlay arch in western Ohio. The arches bordering the Michigan basin are not simple folds as shown by structure contours on top of the Trenton limestone. Local domes and cross folds intersect these major folds and throughout western Ohio many small anticlines and synclines occur along the crest and down the flanks of the Cincinnati arch.

SHOWINGS AND OIL AND GAS PRODUCTION FROM "SUB-TRENTON" ROCKS

Showings of gas were reported in the Mount Simon sandstone in the Voss, Roddenberry, and Meinzinger wells in northeastern Washtenaw County, Michigan. A showing of oil was reported in the Shakopee dolomite in the Sun Oil Company's Kidder and Mead wells in Barry County, Michigan, and showings of oil have been reported in the Trempealeau formation in wells drilled in Jay County, Indiana. Tar residue was found in the Eau Claire and Mount Simon sandstones in the Taylor well, Wayne County, Indiana. A good oil showing in Cambrian rocks was reported in the Shanks No. 6, Kent County, Ontario, and in a well drilled in Osprey Township, Grey County, Ontario, and in the Union Gas Company's Lethbridge No. 1, Middlesex County, Ontario. Several wells penetrating "sub-Trenton" rocks in Ohio had showings of oil and gas (Table II), and east of the Findlay arch[24] (Fig. 1) oil and gas were produced in small areas, named in the following paragraphs.

Tiffin area, Seneca County.—Several wells were drilled through the Trenton and Black River rocks in this area and three wells were productive in the "sub-Trenton" rocks. The best well had a reported initial production of 500 barrels of oil daily. According to Panyity, the wells were on the eastern flank of the

[24] L. S. Panyity, "Oil- and Gas-Bearing Horizons of the Ordovician System in Ohio," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 5 (1921), p. 616.

TABLE II

WELLS WITH OIL AND GAS PRODUCTION OR SHOWINGS BELOW MIDDLE ORDOVICIAN ROCKS

Well No.	County	Location		Well	Depth to Oil (Feet)	Total Depth (Feet)	Initial Production
		Section	Township				
			OHIO				
1	Ashland	1 mi. W. 1¾ mi. N. of SE. corner of township	Ruggles	Ohio Oil-Krause 1	4,420	5,250	Showing
2	Ashland	6	Orange	-Berky 1	4,565	4,717	Showing
3	Crawford	11	Texas	Sun Oil-Riedel 1	2,407	2,433	3 barrels
4	Crawford	18	Lykens	P. Shellhorne	2,510	2,545	Showing
5	Erie	NW. angle of Milan road and Lake Shore R.R.	Huron		2,487	2,960	Showing
6	Fairfield	8	Violet	Community-Stemen	3,229	3,245	Showing
7	Fairfield	At Pickerington	Violet	Stemen 1	3,225	3,235	25 barrels
8	Fairfield	10	Violet	Logan-Fancher 1	3,348	3,412	Showing
9	Hancock	3	Marion	Ohio Oil-Norris 1	1,900	2,980	Showing
10	Henry	24	Harrison	McAffee-Damon 1	2,480	2,513	Showing
11	Huron	2	Peru	C. W. White-Arting 1	3,135	4,270	Showing
12	Licking	Fairgrounds at Newark (2 N., 12 W.)	Newark	Pure Oil-Smith	4,358	4,424	25 barrels
13	Licking	21	Jersey	McClay-Rowe 1	3,962	4,350	Showing
14	Licking	Lot 10	Union	Reese	4,193	4,350	Showing
15	Licking	1½ miles south of Toboso	Hanover	Brill 2	5,155	5,305	Showing
16	Licking	½ mile southeast of Newark	Newark	Wehrle-Zartman 2	4,379	4,605	Oil and gas production
17	Licking	Fairgrounds at Newark	Newark	Wehrle 1	4,354	4,374	Oil and gas production
18	Lorain	Lot 36	Russia	Hanley and Bird-Seaball 1	4,146	4,157	Showing
19	Lorain	Lot 93	Pittsfield	Hanley and Bird-Pitts 1	4,228	4,230	Showing
20	Marion	10	Claridon	Ohio Fuel Supply-Lafferty	2,732	2,762	Showing
21	Marion	10	Claridon	Irey	2,706	2,731	Oil
22	Marion	10	Claridon	Ulsh 1	2,725	2,745	Oil
23	Marion	10	Claridon	Ulsh 4	2,708	2,718	Oil
24	Marion	10	Claridon	Ulsh 5	2,710	2,731	Oil
25	Marion	10	Claridon	Norris 1	2,746	2,750	Oil
26	Pike	1 mile west of Morgantown	Benton	Aurville	1,975	2,275	Showing
27	Pike	At Waverly	Pee Pee	Pera Hatt	2,795	3,360	Showing
28	Putnam	4	Perry	Pember-Myers 1	1,432	1,450	Showing
29	Seneca	27	Pleasant	Sun Oil-Mavle 1	2,160	2,250	150 barrels
30	Seneca	33	Pleasant	Spohn and Wade-Tomb 1	2,057	2,073	Showing
31	Seneca	7	Clinton	Sun Oil-Crum 2	2,075	2,221	Showing
32	Wayne	14	Wooster	Ohio Oil-Armstrong 8	5,763	6,116	Showing

TABLE II—(*continued*)

Well No.	*County*	*Location*		*Well*	*Depth to Oil (Feet)*	*Total Depth (Feet)*	*Initial Production*
		Section	*Township*				
			MICHIGAN				
33	Barry	8	T. 3 N., R. 9 W.	Sun Oil-Kidder 1	4,991	5,013	Showing
34	Barry	10	T. 3 N., R. 9 W.	Sun Oil-Mead 1	5,079	5,116	Showing
35	Monroe	29	T. 5 S., R. 10 E.	Sturman-Chapman 1	3,005	3,376	Showing
36	Washtenaw	12	T. 2 S., R. 7 E.	Colvin-Meinzinger 1	5,231	5,692	Showing
37	Washtenaw	16	T. 1 S., R. 7 E.	Colvin-Voss 1	(5,210 (6,150 (6,320	6,410	Showing
38	Washtenaw	27	T. 1 S., R. 7 E.	Colvin-Rodenberry 1	5,917	6,085	Showing
			INDIANA				
39	Jay	29	T. 24 N., R. 13 E.	Petroleum Development-Binegar 1	3,367	3,404	Showing
40	Jay	Redkey, Indiana		Old well			Reported showing
			ONTARIO, CANADA				
41	Grey	Lot 10, Concession 11	Osprey		in Cambrian	1,760	Showing
42	Kent	Lot 188, Concession NTR	Romney	Southern Ontario Gas-Shanks 6	in Cambrian	3,560	Showing
43	Middlesex	Lot 7, Concession 5	Ekfrid	Union Gas-Lethbridge 1	in Cambrian	3,535	Showing

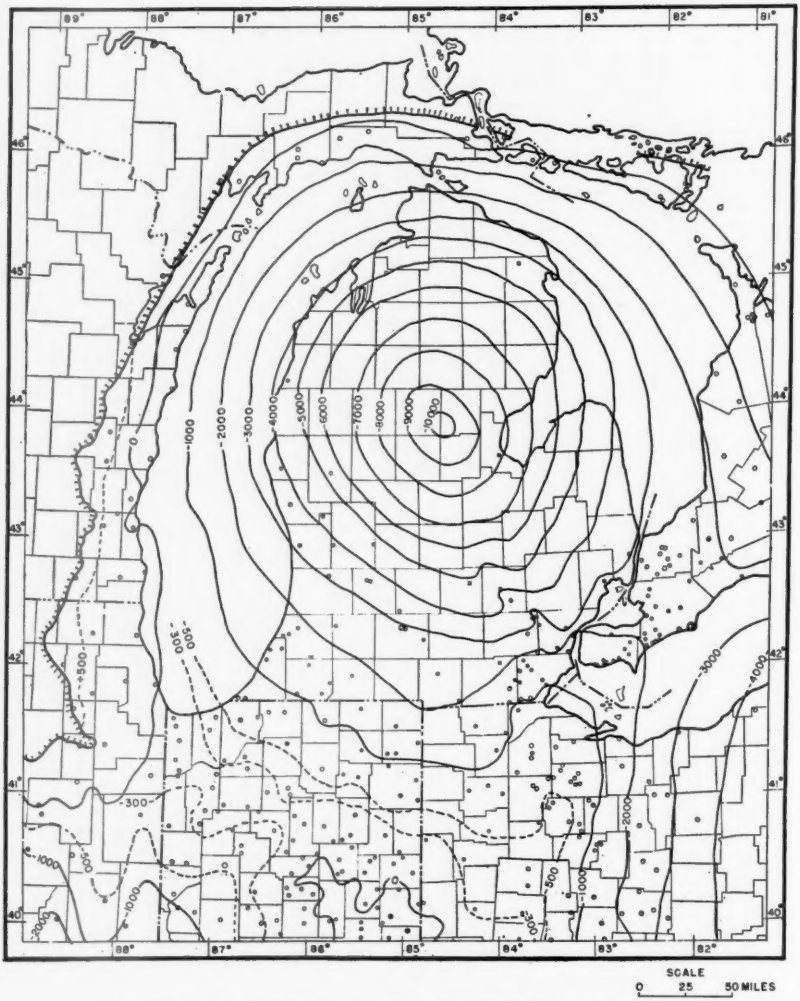

FIGURE 9. CONTOURS ON TOP OF TRENTON LIMESTONE

DATUM, SEA LEVEL

CONTOUR INTERVAL 1000 FEET

+500, −300 AND −500 CONTOURS ADDED

BOUNDARY OF TOP OF TRENTON LIMESTONE AT SURFACE

CONTROL POINT

TABLE III

LIST OF WELLS IN FIGURES 8 AND 9

Wells and Number of Well in Cross Section	*Location* *Section*	*Township*	*Range*
Livingston County, Michigan			
1. Duck Lake Oil Co.-McPherson 1	35	3N.	4E.
Washtenaw County, Michigan			
2. Colvin-Voss 1	16	1S.	7E.
3. Colvin-Meinzinger 1	12	2S.	7E.
Wayne County, Michigan			
4. Colvin-Theison 1	16	4S.	9E.
Monroe County, Michigan			
5. Sturman-Chapman 1	29	5S.	10E.
Essex County, Ontario			
6. Union Gas-Imperial Oil 3	Lot 14	Concession 11	
Kent County, Ontario			
7. Dominion Gas Co.-Shanks 6	Lot 184	Concession NTR	
Geauga County, Ohio	Lot 1		
8. East Ohio Gas Co.-Crile 1	Tract 4	9N.	8W.
Jay County, Indiana			
9. Petroleum Development Corp.-Binegar 1	29	24N.	13E.
Putnam County, Ohio			
10. Ohio Oil Co.-Barlage 1	29	2N.	7E.
Wood County, Ohio			
11. Schwyn-Brailey 8	12	4N.	10E.
Sandusky County, Ohio			
12. Ohio Oil Co.-Bruns 1	9	5N.	13E.
Seneca County, Ohio			
13. Ohio Oil Co.-Bishop 1	13	2N.	16E.
Ashland County, Ohio			
14. Ohio Oil Co.-Krause 1	14	1N.	20W.
Wayne County, Ohio			
15. Ohio Oil Co.-Armstrong 8	14	15N.	13W.

Tiffin anticline approximately 100–200 feet structurally lower than the top of the anticline.

Caledonia area, Marion County.—Four producing wells had initial yields varying from 15 to 745 barrels daily. Structural accumulation of the oil in the "sub-Trenton" rocks is indicated in this area.

Pickerington area, Fairfield County.—One well had an initial production of approximately 8 barrels of oil daily. Two near-by wells obtained only showings of oil.

Newark area, Licking County.—A few wells near Newark produced oil and and gas from "sub-Trenton" rocks. One well initially produced 25 barrels daily.[25]

[25] G. D. Lindberg, personal communication.

OIL AND GAS PRODUCTION FROM MIDDLE ORDOVICIAN ROCKS

The largest area of Trenton production is the Lima-Indiana field which extends across northwestern Ohio into Indiana. Gas was first produced in 1884 near Findlay, Ohio, and was produced in 1886 at Kokomo, Indiana. More than 100,000 wells have been drilled in the field and 480,000,000 barrels of oil have been produced from approximately 577,000 acres.[26] Although the average recovery of oil from the Trenton in this field is approximately 830 barrels per acre, recovery is as much as 3,500 barrels per acre in some areas. The initial daily yields of the best wells in the field were 5,000–6,000 barrels. Oil produced from at least three zones of dolomitized limestone. The most productive zone is 20–25 feet thick and is in the upper 50 feet of the Trenton. Other producing zones were at depths of approximately 200 and 400 feet below the top of the Trenton. Dolomitization of the Trenton and Black River limestones along the Findlay arch may have been caused in part by the Bowling Green fault and possibly by other fractures of the rocks in the producing area which permitted ascending solutions to alter the limestone vertically and horizontally. Landes[27] believes that local dolomitization, which has developed local porosity in the Lima-Indiana field, and Adams and Deep River fields, Michigan, was produced by ascending solutions that had passed through older dolomites and had picked up magnesium from them. The dolomite in the producing zones contains irregular areas of porosity as shown by rock fragments from the producing wells. Some fragments were perforated by small holes the size of a pin and the intervening rock is hard and compact. Other specimens are porous on one side and dense on the other side. Honeycomb structures with openings several inches long were observed in some fragments blown out of the wells at the time of shooting.[28] In the field there are areas in which no oil or gas was produced although the elevation of the top of the Trenton is about the same as in the producing area.

Salt water is commonly associated with the oil in the porous zones of the Trenton.

OTHER AREAS OF TRENTON PRODUCTION

Small areas of Trenton oil and gas production have been found along the southern border of the Michigan basin in northwestern Ohio and northeastern Indiana and along the Kankakee arch through northwestern Indiana (Fig. 1).

Trenton production in Michigan has been only in the southeastern part of the state in Monroe and Wayne counties. Oil and some gas are produced from the Trenton in the Deerfield field in Dundee Township, Monroe County, at a depth of 2,050 feet. The field was discovered in 1920 but development was not

[26] Data from Ohio Oil Company, Findlay, Ohio, and Division of Geology, Indiana Department of Conservation.

[27] K. K. Landes, "Porosity Through Dolomitization," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 30, No. 3 (1946), p. 317.

[28] J. A. Bownocker, "The Occurrence and Exploitation of Petroleum and Natural Gas in Ohio," *Ohio Geol. Survey Bull. 1* (1903), 4th Ser., pp. 31–101.

active until after 1939. More than 400,000 barrels of oil have been produced from the 33 successful wells drilled in the field. The initial daily yields of the wells range from 4 to 800 barrels. Producing zones, which were in the dolomitized part of the limestone, were found at depths varying from 3 to 120 feet below the top of the Trenton. Oil and gas were produced from the porous zones on the flanks of the Deerfield anticline.

The other areas of Trenton production in southeastern Michigan are the Sumpter field in Sumpter Township and the New Boston field in Huron Township, Wayne County. Two wells were drilled in 1942 in the New Boston field in Sec. 18, Huron Township. The initial production of each well was 10 barrels and the producing zone was reached at a depth of 120 feet in the Trenton. A well was completed in 1941 in Sec. 22, Sumpter Township, initially producing 12 barrels of oil with water. Oil was produced at depths of 10–17 feet and 43–74 feet from the top of the Trenton.

Showings of oil and gas were reported from the Trenton in wells in southern Michigan. Small showings of oil were found at depths of 19 and 35 feet from the top of the Trenton in a well drilled in the southeastern part of Drummond Island, Chippewa County, and in dolomite 150 feet below the top of the Trenton in Garfield Township, Mackinac County, in the Northern Peninsula.

Oil and gas have been produced from the Trenton and Black River strata in widely separated areas in Ontario, Canada. The Dover field, Kent County, is the most important area of Trenton gas and oil production in western Ontario (Fig. 1). It was discovered in 1917, and has produced more than 9 billion cubic feet of gas and 200,000 barrels of oil, and now has about 8 oil wells and 3 gas wells in operation.[29] The field is in a syncline[30] and the porosity is believed to be due to faulting.[31] Recent studies[32] are in accord with earlier findings regarding the occurrence of oil and gas production in the field. Oil and gas are produced at depths 282 feet and 400 feet below the top of the Trenton.[33]

Natural gas is produced in the Hepworth field in Bruce County, which was discovered in 1900 and which has produced approximately 70 million cubic feet of gas.[34] Gas is produced from Black River rocks at a depth of 460 feet below the top of the Trenton.[35]

A little oil was produced from the Trenton in small areas on Manitoulin

[29] C. S. Evans, personal communication.

[30] M. Y. Williams, "Oil Prospects of Southwestern Ontario," *Canada Geol. Survey Sum. Rept.*, Pt. E (1917), p. 25.

[31] R. B. Harkness, "The Oil and Gas Fields of Ontario," *Ontario Dept. Mines Rept.*, Vol. 37, Pt. 5 (1928), p. 74.

[32] C. S. Evans, personal communication.

[33] G. S. Hume, "Oil and Gas in Eastern Canada," *Canada Geol. Survey*, Econ. Ser., No. 9 (1932), p. 83.

[34] C. S. Evans, personal communication.

[35] G. S. Hume, *op. cit.*, p. 84.

Island (Fig. 1). The oldest wells were drilled in 1905–1907; later drilling was done in 1909 and from 1912 to 1920,[36] and the most recent producing wells were completed in 1940. The depth to the top of the Trenton is 115–517 feet and the producing zone is generally 12–20 feet below the top of the Trenton, although in some wells it is more than 160 feet below the top of the Trenton. One well was reported to have made 45 barrels of oil in 15 minutes and another 50 barrels in 12 hours. Apparently the wells soon produced too much water for economic operation.

OIL AND GAS POSSIBILITIES

Approximately 4,000 feet of Lower Ordovician and Cambrian rocks have thinned and are eroded eastward toward the Findlay arch and these strata are absent in parts of southwestern Ontario. As showings of oil and gas have been found in wells penetrating these rocks on the flanks of structural highs, stratigraphic and porosity traps may be found in the truncated beds along the major folds in and bordering the Michigan basin.

As no major unconformities are in the Trenton and Black River rocks in the Michigan basin and porosity is apparently associated with fracturing and dolomitization of limestone, the possibility of further oil discoveries in these strata is dependent on porosity on top or on the flanks of domes and anticlines. As oil and gas have been produced at various depths in the Trenton and Black River rocks where dolomitization has occurred, the full sequence should be drilled for adequate testing.

[36] M. Y. Williams, "General Geology and Petroleum Resources of Manitoulin and Adjacent Islands, Ontario," *Canada Geol. Survey Paper 37-25* (1937), pp. 33–50.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 8 (AUGUST, 1948), PP. 1449-1456, 3 FIGS., 1 TABLE

NEW YORK SUBSURFACE GEOLOGY[1]

E. T. HECK[2]
Bradford, Pennsylvania

ABSTRACT

This paper summarizes the data available on the Trenton and sub-Trenton formations as shown in wells in New York state. Approximately a score of wells have been reported to have reached the Basement complex and nearly all have been near the Great Lakes or the Adirondack pre-Cambrian area. The relationship of the rocks east and west is shown by means of a cross section. Contour maps show the approximate sub-sea elevation of the top of the Trenton and the top of the pre-Cambrian.

INTRODUCTION

This paper is a summary of information on the Trenton and sub-Trenton formations as shown in the wells of New York state. The data are not original with the writer; they have been assembled from several sources. The available records on the general geology of New York have been examined, and this study supplemented by discussion with geologists who know the state best. It is not possible to list individuals who have contributed to this study, but special mention is due the State paleontologist, Winifred Goldring, the retired State geologist, C. A. Hartnagel, and the assistant State geologist, John G. Broughton.

In other sections of this symposium both Fettke and Swartz show geologic columns that apply to the New York area. In order to avoid duplication, the reader is referred to those sections for such data. In the following discussion several of the formation names applied at the outcrop are omitted. This is so because it is impossible to make detailed correlations from the data available.

GENERAL DISCUSSION

In the state of New York approximately a score of wells have been drilled to the Basement complex. Nearly all of these wells were drilled near the Great Lakes, or close to the Adirondack pre-Cambrian area (Fig. 1). Most of the wells were drilled several years ago and samples of only a few are available. So far as known to the writer, no systematic study of all available samples has been made. A few of these cuttings were examined during the present study.

Several of the wells drilled a "wash" zone 5–50 feet thick just above the true pre-Cambrian. Because of the presence of igneous and metamorphic rock fragments, this zone has frequently been erroneously assigned to the pre-Cambrian. In some wells the detritus in this zone is extremely coarse, which indicates that there may have been appreciable topographic relief at the beginning of Paleozoic deposition. In general, however, the present dip of the pre-Cambrian surface appears to correspond with that of the early Paleozoic sediments.

The oldest Paleozoic formation drilled in western New York is probably that

[1] Manuscript received, February 28, 1948.

[2] Chief geologist, Quaker State Oil Refining Corporation.

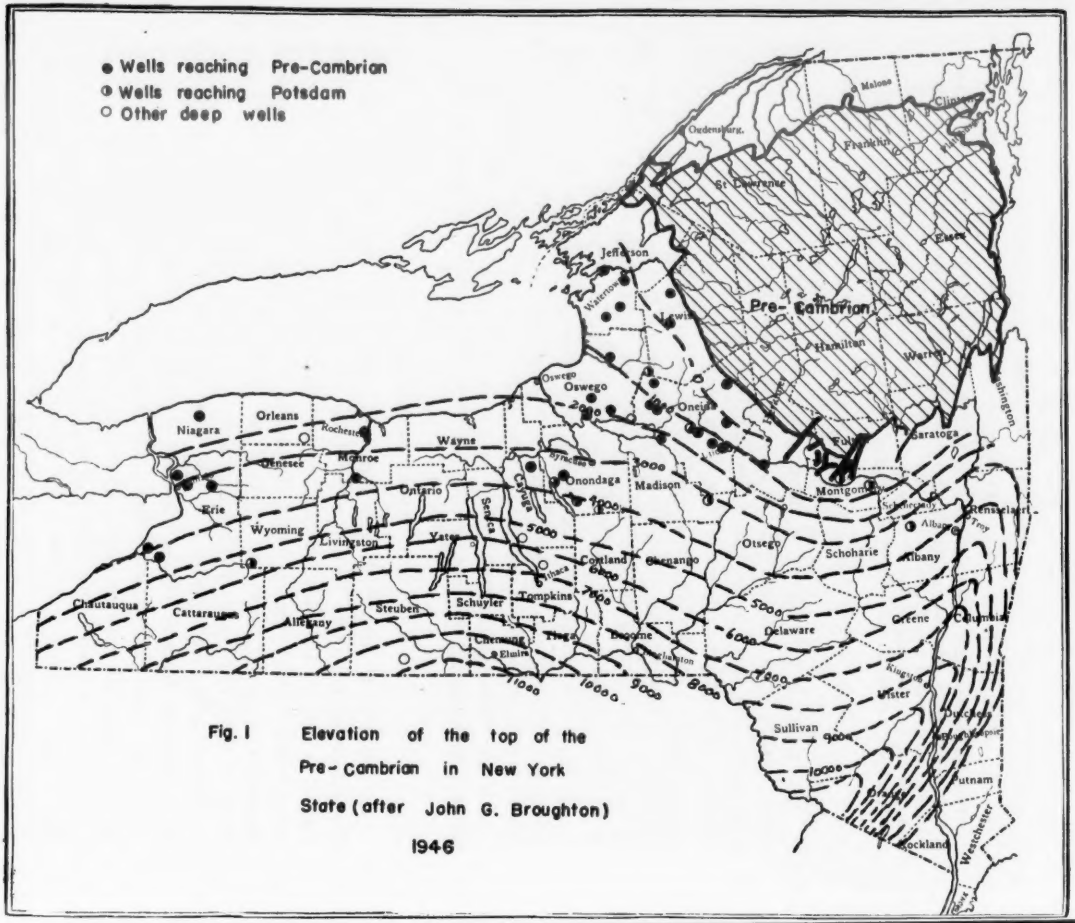

Fig. 1 Elevation of the top of the Pre-Cambrian in New York State (after John G. Broughton) 1946

reported by Krynine[3] in the K. R. Wilson well in Arcade Township, Wyoming County. Krynine's report reads in part as follows.

> Down to approximately 7,135 feet the well is still running within the Potsdam sand with a pretty good porosity. At that depth the sand changes and begins to pass into a greenish chalcedonic chert. This chert is solid from 7,138 feet down. This greenish chert contains between 5 and 10 per cent of chloritic flakes. At first sight it has a pre-Cambrian appearance and suggests a metamorphic rock. However, after careful examination it proves to be a normal sedimentary chert and the chlorite proves to be biotite, altered to chlorite by normal sedimentary diagenetic processes.
>
> Upon petrographic examination of the heavy residue, the chert can be seen to contain a varied suite of igneous minerals, all of which strongly indicate the presence of possibly as many as two types of volcanic ash that fell in the sea during the formation of this chert. This makes it possible to correlate this chert with the lower upper or middle Cambrian Warrior limestone of central Pennsylvania which also carries a large amount of volcanic ash of a type similar to that found in the chert of the Arcade well. This correlation can be seen from the detailed petrographic analysis included in the report.
>
> The Potsdam sandstone, hence, seems to end at 7,135 feet and has a total thickness in the Arcade well of 840 feet, which thickness can be divided into at least two members, namely, the first and second Potsdam sand, and possibly into three sands if the second Potsdam be further subdivided. The stratigraphic equivalent of the Potsdam in central Pennsylvania is the Gatesburg formation, 1,600 feet thick.

Prior to the foregoing report, it was generally believed that the Potsdam sandstone was the oldest Paleozoic formation in western New York.

The thickness of the Potsdam sandstone ranges from that shown in the Wilson well to nearly zero, and the formation is absent at the surface northeast of Utica. Where thickest, the formation contains numerous layers of dolomite, and all gradations between pure sandstone and pure dolomite are found. It is probable that the formation transgresses time boundaries from one region to another. So far as known to the writer, every well that has penetrated the Potsdam in western New York has found one or more permeable zones as shown by the production of fluids. These permeable zones ordinarily show a very high percentage of well rounded quartz grains with pitted ("etched" or "frosted") surfaces and little cement. In other zones the grains may be firmly cemented by silica or dolomite.

In the Wilson well 985 feet of calcareous rocks overlie the Potsdam. In the vicinity of the eastern end of Lake Ontario, the thickness of calcareous rock in very few places is as much as 800 feet and southeastward in Oneida and Herkimer counties the thickness is less than 500 feet. Most of the change in thickness is due to the fact that eastward the upper layers pass into shale. The lower beds in this zone are everywhere dolomitic and may be nearly pure dolomites. In some areas, particularly in the vicinity of Oneida and Herkimer counties, these beds contain appreciable percentages of well rounded, pitted quartz grains. The grains are distributed through the rock in a manner that suggests that they were either blown into the basin of deposition or that the entire rock has a clastic origin. In

[3] Paul D. Krynine, special report to the Quaker State Oil Refining Corporation, dated March 23, 1946.

such areas it is difficult or impossible to recognize the top of the Potsdam with any precision.

The top of the aforementioned calcareous zone in wells is generally called the top of the Trenton. In a few wells various workers have attempted to divide the zone to show the major divisions known at the outcrop (Trenton, Black River, Chazy, Beekmantown, Little Falls), but such attempts have not been very successful. The Trenton is productive in the vicinity of the eastern end of Lake Ontario where it consists of dark gray limestone containing several thin beds of black or dark gray shale.

Overlying the Trenton is a thick zone of shale. This shale is dark gray or black at the base and becomes light gray and silty at the top. In the Wilson well this zone is 850 feet thick. Like the underlying Trenton it is doubtful that this zone

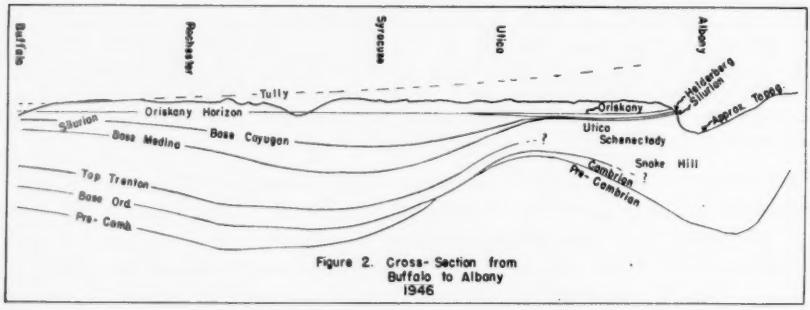

Figure 2. Cross-Section from Buffalo to Albany 1946

can be divided into the same divisions used at the outcrop (Lorraine, Utica, *et cetera*).

The Oswego and Queenston formations overlie this shale zone wherever these formations are present. There is little difference in the two formations excepting in color. Both thin and become more shaly toward the west and north; both consist of interbedded sandstones and shales; and both are absent by unconformity in east-central New York. The Queenston is predominantly red but may contain greenish gray layers. The Oswego is greenish gray. The Queenston marks the top of the Ordovician system in the state.

The relationship of the various formations in an east-west section is shown in Figure 2. The town names across the top of the figure are included for reference only since the cross-section line is drawn somewhat south of these towns. The section is not drawn to illustrate structural relationships and the vertical scale is approximately 40 times the horizontal. The important features are the disappearance of the Cambrian beds and the marked thinning in the region south and east of Utica. This is in approximately the same region where Marshall Kay has named the Adirondack axis. In this region also the Medina formation is missing and the Silurian Oneida conglomerate is resting on dark gray shales of Ordo-

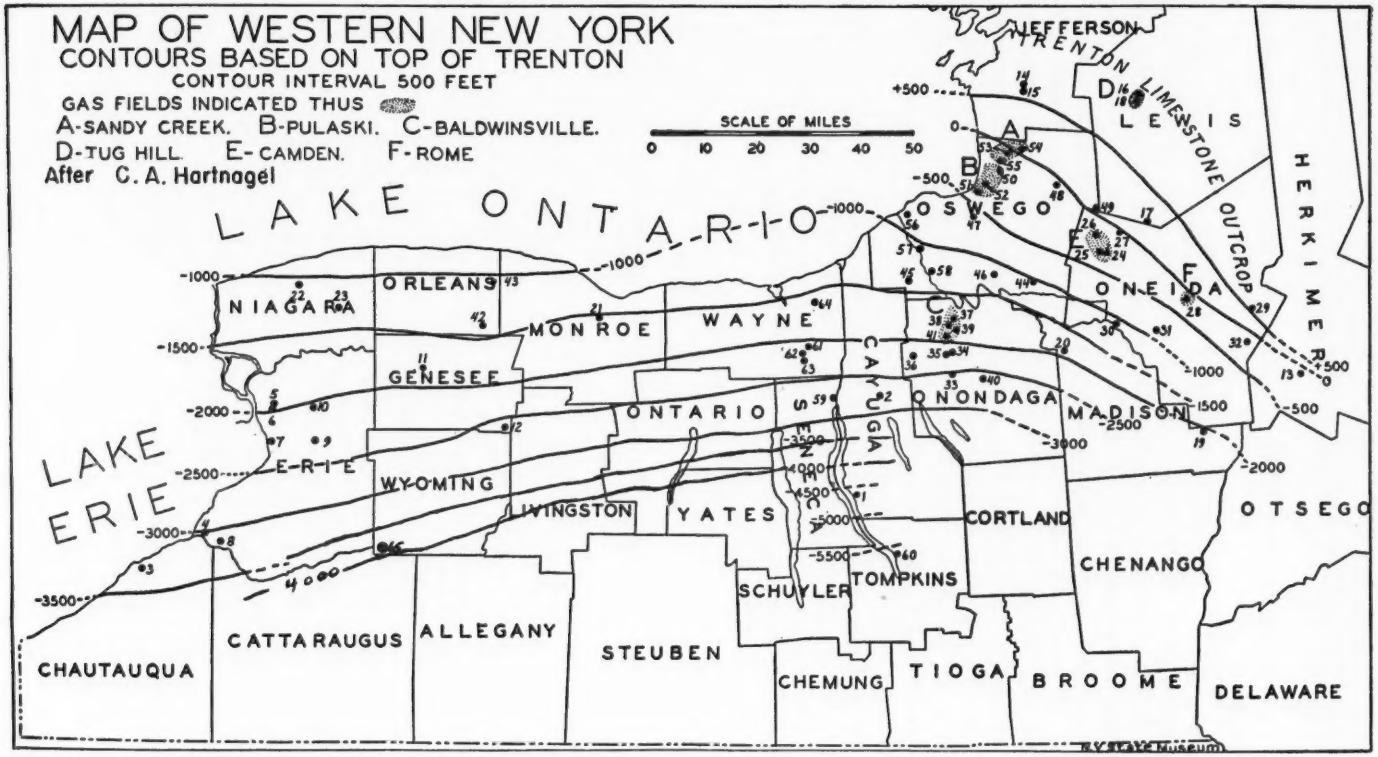
MAP OF WESTERN NEW YORK
CONTOURS BASED ON TOP OF TRENTON
CONTOUR INTERVAL 500 FEET
GAS FIELDS INDICATED THUS
A-SANDY CREEK. B-PULASKI. C-BALDWINSVILLE.
D-TUG HILL. E-CAMDEN. F-ROME
After C. A. Hartnagel
SCALE OF MILES
0 10 20 30 40 50
LAKE ONTARIO
LAKE ERIE
JEFFERSON
TRENTON LIMESTONE OUTCROP
LEWIS
HERKIMER
OSWEGO
ONEIDA
NIAGARA
ORLEANS
MONROE
WAYNE
GENESEE
ONTARIO
ONONDAGA
MADISON
WYOMING
LIVINGSTON
YATES
CAYUGA
CORTLAND
OTSEGO
CHENANGO
SCHUYLER
TOMPKINS
CHAUTAUQUA
CATTARAUGUS
ALLEGANY
STEUBEN
CHEMUNG
TIOGA
BROOME
DELAWARE
N.Y. State Museum

FIG. 3

vician age. There is apparently no representative of the Oswego or Queenston formations.

STRUCTURE AND PRODUCTION

Figure 3 shows the structural position of the top of the Trenton as revealed in wells. Also shown are the locations of the wells used in compiling the map. The data used are shown in Table I.

As described in preceding paragraphs the top of the Trenton, as recognized in the wells, is probably not a time boundary and the top bed may be older in the eastern part of the area than it is in the western part. So far as can be determined, the structure is that of a rather simple uniform south dip. It should be pointed out, however, that there is no information in the part of the state where the surface beds are known to be folded to an appreciable degree. There is some doubt that the Trenton structure corresponds with the structure shown on the Oriskany in the southern part of the state.

The productive areas are indicated in Figure 3 by closely spaced dots and large letters. The specific information about each field is not repeated here since it can be found in the paper written by Hartnagel listed in the references at the end of this paper. As shown, all fields are near the eastern end of Lake Ontario. Pro-

TABLE I

Map No.	*County*	*Township*	*Name of Well*	*Elevation (Feet)*	*Depth to Trenton (Feet)*	*Elevation of Top of Trenton (Datum: Sea-Level)*
1	Cayuga	Ledyard	Mahaney	830	5,501	−4,671
2		Throop	Old Auburn	560	3,327	−2,767
3	Chautauqua	Dunkirk	Cassety	660	4,010	−3,350
4	Erie	Brant	Bemus Pierce	740	3,750	−3,010
5		Buffalo	City Hospital, No. 1	680	2,600	−1,920
6		Buffalo	City Hospital, No. 2	680	2,665	−1,985
7		Buffalo	South Park	600	2,960	−2,360
8		Collins	George Button	660	3,835	−3,175
9		Elma	Spring Brook	800	3,100	−2,300
10		Lancaster	Depew	680	2,855	−2,175
11	Genesee	Batavia	Gibson	870	2,750	−1,880
12		Pavilion	Martin	1,120	3,720	−2,600
13	Herkimer	German Flats	Old Ilion	405	475	− 70
14	Jefferson	Adams	White No. 1	605	6	+ 599
15		Adams	White No. 2	623	33	+ 590
16	Lewis	Harrisburg	Nefsey No. 1	1,700	602	+1,098
17		Lewis	Aikens	1,340	1,082	+ 258
18		Martinsburg	Finn	1,752	726	+1,026
19	Madison	Brookfield	Letts	1,220	3,328	−2,108
20		Sullivan	Chittenango	444	2,450	−2,006

TABLE I—(*continued*)

Map No.	*County*	*Township*	*Name of Well*	*Elevation (Feet)*	*Depth to Trenton (Feet)*	*Elevation of Top of Trenton (Datum: Sea-Level)*
21	Monroe	Rochester (City)	Old Rochester	506	2,006	−1,500
22	Niagara	Newfane	Coomer	340	1,435	−1,095
23		Royalton	Gasport	519	1,800	−1,281
24	Oneida	Camden	Donlon	623	935	− 312
25		Camden	Rinkle	597	928	− 331
26		Florence	Comins	913	1,164	− 251
27		Florence	Hanifan	1,122	1,165	− 43
28		Rome	Ringdahl	485	525	− 40
29		Trenton	E. D. Morgan	900	320	+ 580
30		Verona	Ainsworth	400	1,520	−1,120
31		Verona	Dodge	520	1,400	− 880
32		Utica (City)	Standard Harvester	455	562	− 107
33	Onondaga	Camillus	E. K. Monroe	861	3,350	−2,489
34		Camillus	Portland Cement	415	2,696	−2,281
35		Camillus	Sherwood	480	2,700	−2,220
36		Elbridge	Ashby	425	2,618	−2,193
37		Lysander	Kendall	410	2,250	−1,840
38		Lysander	Monroe	420	2,250	−1,830
39		Lysander	Names	430	2,270	−1,840
40		Onondaga	Yenny	1,013	3,730	−2,717
41		Van Buren	Spaulding No. 2	425	2,404	−1,979
42	Orleans	Clarendon	Emilkampf	660	1,972	−1,312
43		Murray	Holley	370	1,420	−1,040
44	Oswego	Constantia	Parker	500	1,535	−1,035
45		Granby	Leo Gray	409	1,700	−1,291
46		Hastings	Rice	420	1,609	−1,189
47		Mexico	Earl	350	1,027	− 677
48		Orwell	Phineas	900	926	− 25
49		Redfield	Ciaccio	1,165	1,040	+ 125
50		Richland	Maltby	355	515	− 160
51		Richland	H. Manwaring	281	651	− 370
52		Richland	Stewart No. 1	345	585	− 240
53		Sandy Creek	Beldock	480	520	− 40
54		Sandy Creek	Kinney	780	630	+ 150
55		Sandy Creek	Woodard No. 1	290	400	− 110
56		Scriba	Oswego City	300	1,196	− 896
57		Volney	E. Van Buren	320	1,370	−1,050
58		Volney	Vogelsand No. 1	380	1,400	−1,020
59	Seneca	Tyre	Tyre	402	3,000	−2,598
60	Tompkins	Lansing	Farkas	850	6,376	−5,526
61	Wayne	Galen	Ethel Arnold	461	2,540	−2,079
62		Galen	Harper No. 3	405	2,590	−2,185
63		Galen	Noble	410	2,630	−2,220
64		Wolcott	Wolcott	317	1,950	−1,633
65	Wyoming	Arcade	K. R. Wilson	1,460	5,342	−3,882

duction is from the Trenton limestone and is scattered in small producing zones throughout a gross thickness of approximately 600 feet. In the productive area the Trenton consists of dark gray limestone containing several thin beds of black or dark gray shale. The open flow of several of the wells was relatively large and has been estimated as being from one to several million feet per day. These large flows are very short lived and the general rule is that a small production will be continued for a number of years. Most striking are the abnormally high pressures encountered. In the Baldwinsville field, a well 2,500 feet deep gave a recorded pressure of 1,450 pounds. In the old Fulton field in Oswego County, a well 1,700 feet deep showed a pressure of 1,525 pounds. The excessive pressures and the extremely short life of the large open flows suggest that the early production may come from joints or bedding planes that close as soon as the gas pressure has been released. Per-acre yield of gas is not available but is known to be small. Drilling the past few years has indicated that in some areas the wells have not drained any large area and this fact also supports the idea that the production is not from normally permeable sections. South of Pulaski two wells have reported non-commercial amounts of gas in the Potsdam sandstone. One well near Warners, Onondaga County, reported a flow in excess of 100,000 cubic feet daily and had rock pressure of 800 pounds. The Potsdam was found at a depth of 3,580 feet.

CONCLUSIONS

As shown by the contours in Figure 1, a pre-Cambrian high probably extends southwest from Fulton County through Delaware County. This approximately coincides with the general location of the Adirondack axis as defined by Kay. The area has not been prospected and there is no absolute proof of the presence of this high. Excepting in the vicinity of the Great Lakes the Trenton and sub-Trenton beds are imperfectly known and inadequately tested.

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 8 (AUGUST, 1948), PP. 1457-1492, 7 FIGS.

SUBSURFACE TRENTON AND SUB-TRENTON ROCKS IN OHIO, NEW YORK, PENNSYLVANIA, AND WEST VIRGINIA[1]

CHARLES R. FETTKE[2]
Pittsburgh, Pennsylvania

ABSTRACT

Exploration of Trenton and sub-Trenton rocks in the northern part of the Appalachian basin has been confined mainly to the shallower parts across central Ohio, southwestern Ontario, and western and central New York. Only a few wells have penetrated these rocks in the deeper parts of the basin. The salient features that have been revealed by the drilling are presented and discussed.

Maps showing the regional structure on the top of the Trenton limestone and the thicknesses of the Middle and the Upper Ordovician series in the northern part of the basin have been prepared. The lithologic characteristics of the Trenton and sub-Trenton formation across the northern part of the basin are described in six well-sample records. Their development underneath the area is shown by four series of stratigraphic sections based on well-sample records and drillers' logs.

Data are presented indicating that the dolomitic sandstones and sandy dolomites underlying the pre-Black River unconformity in central and northeastern Ohio and northwestern Pennsylvania, heretofore correlated with the St. Peter sandstone, do not represent a single geologic horizon but become progressively younger in a southerly direction in central Ohio.

Possibilities of the Trenton and sub-Trenton formations as potential sources of oil and gas are discussed.

INTRODUCTION

Trenton and sub-Trenton rocks underlie the strata from which the oil and gas of the Appalachian province have been produced. They constitute the lower part of the sedimentary section that overlies the pre-Cambrian in the Appalachian basin. Although the quantities of oil and gas that have been obtained from this part of the section in the Appalachian basin to date have been almost negligible, rocks of similar age have been prolific producers of both oil and gas in adjacent areas as well as other parts of the United States. Oil and gas reserves in the higher strata of the Appalachian province are dwindling rapidly and unexplored areas in them in which new discoveries of significant size may be expected are definitely limited. The time has come when the potentialities of the deeper strata need to be explored.

In the present paper the writer has brought together the salient features that have been revealed by deep exploration in central and eastern Ohio, southwestern and south-central New York, western Pennsylvania, and northwestern West Virginia. The area covered includes a large part of the northwestern flank of the Appalachian basin. Most of the exploration in Trenton and deeper strata

[1] Manuscript received, February 28, 1948. Published by permission of the director of the Pennsylvania Bureau of Topographic and Geologic Survey.

[2] Professor of geology, Carnegie Institute of Technology. Co-operating geologist, Pennsylvania Topographic and Geologic Survey. In connection with the preparation of the paper, the writer wishes to thank the individuals and companies who furnished the samples, well records, and other data on which the study is based. He is particularly indebted to Kenneth Cottingham of the Ohio Fuel Gas Company who provided well elevations, drillers' logs and a map showing locations of Trenton and sub-Trenton wells in central and eastern Ohio; and Robert G. Kurz and George T. Thomas of the Ohio Oil Company who made available their company's file of drillers' logs and several excellent sets of drill-cutting samples. The work on which the paper is based was done in connection with subsurface studies that the writer is making for the Pennsylvania Topographic and Geologic Survey.

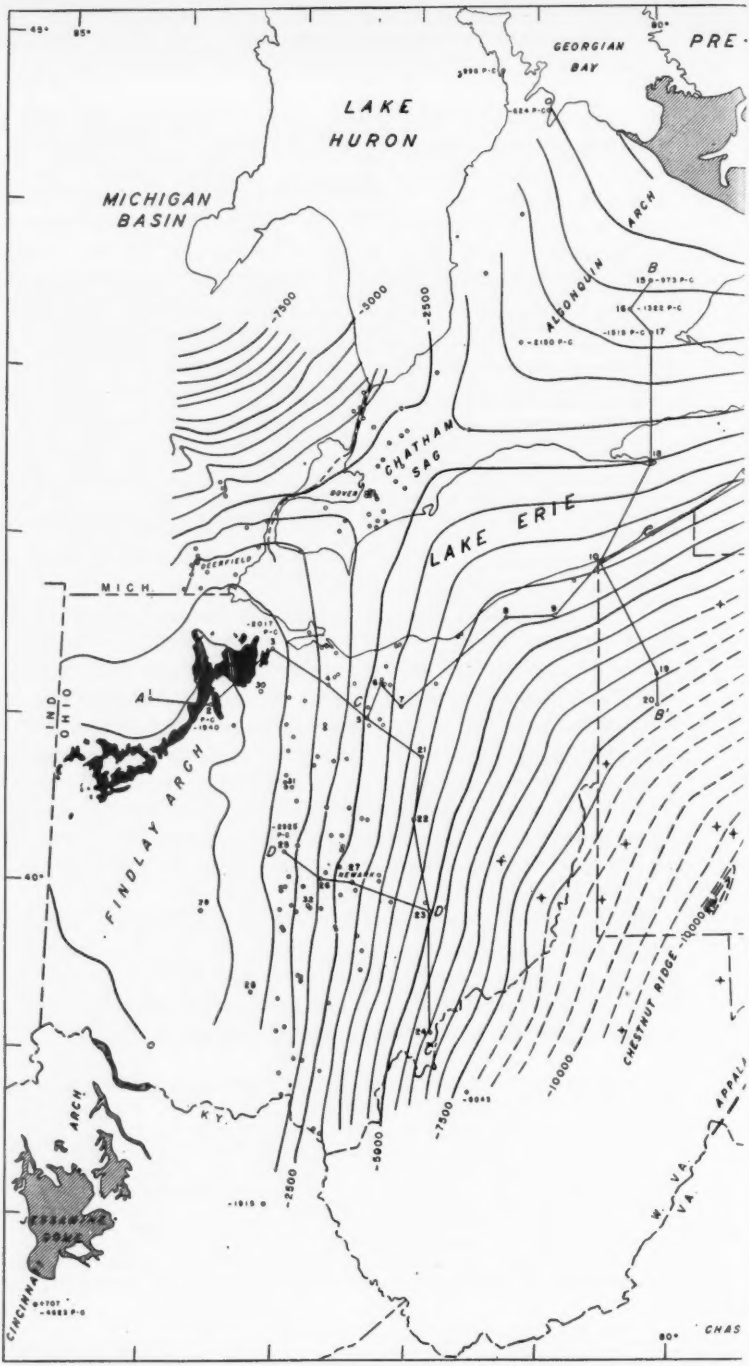
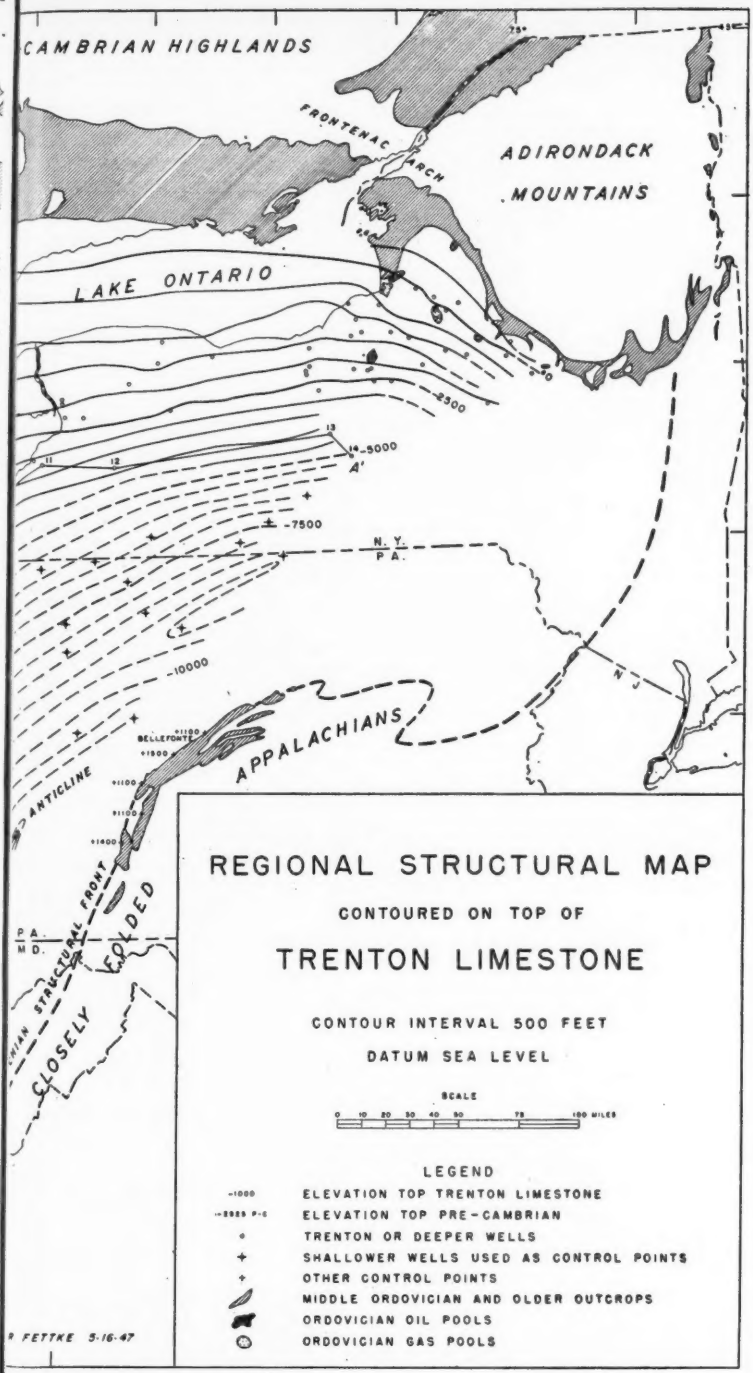


FIG. 1.—Regional structural map of



northern part of Appalachian basin.

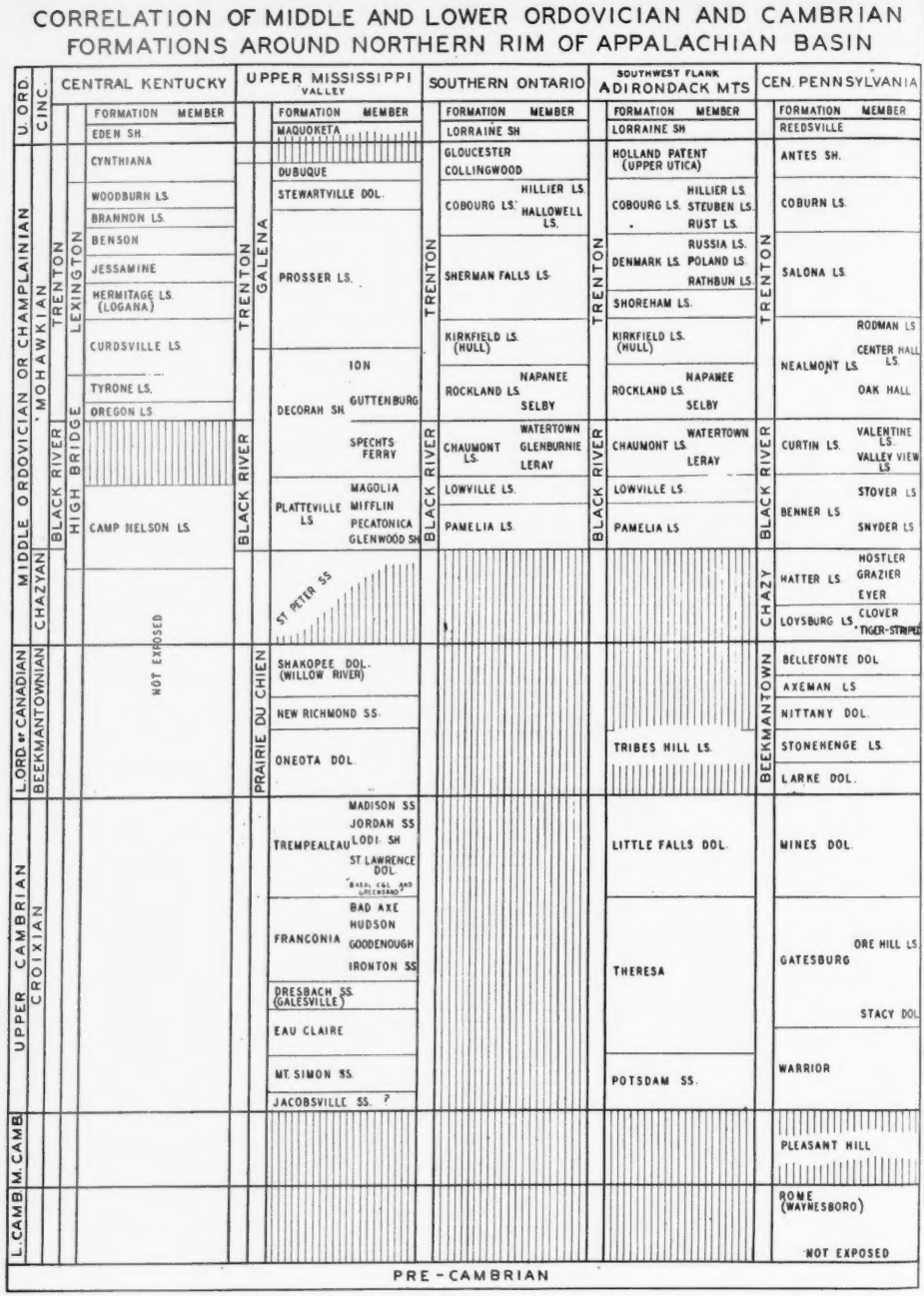


FIG. 2.—Correlation chart of Middle and Lower Ordovician and Cambrian formations around northern rim of Appalachian basin.

has been confined to the outer, relatively shallow margin. Very few wells have been drilled to the Trenton in the deeper parts of the basin. Only five have reached this formation west of the Allegheny front in Pennsylvania and one in West Virginia. Of those in Pennsylvania, three were drilled through the Trenton and Black River groups of the Middle Ordovician and two reached strata of Cambrian age.

STRATIGRAPHY

Upper Cambrian strata rest on pre-Cambrian rocks in the northern part of the Appalachian basin over all but a relatively narrow belt along the northern margin in the vicinity of Lake Ontario where Middle Ordovician beds overlap the Cambrian and rest directly on the pre-Cambrian. Lower Ordovician rocks at the north end of the basin are confined mostly to the eastern part. Middle Ordovician limestones, both Black River and Trenton, extend over the entire area.

OUTCROPS

Outcrops of Trenton and sub-Trenton rocks around the margins of the northern Appalachian basin (Fig. 1) are confined to central Kentucky, southern Ontario, the southwestern flank of the Adirondack Mountains, and the intensely folded and faulted belt east of the Appalachian structural front in eastern New York, northern New Jersey, and central Pennsylvania. They are under cover on the northwest side of the basin over the Findlay arch which separates the Appalachian from the Michigan basin. In this direction they appear first at the surface on the west and northwest margins of the latter basin on the flanks of the Wisconsin arch.

The classification and correlation of the Trenton and sub-Trenton rocks as they are developed on the outcrop in areas adjacent to the Appalachian basin are shown in Figure 2. The chart has been compiled from data obtained from a study of the recent literature covering the areas involved. No attempt has been made to indicate relative thicknesses of the various formations. The closely spaced vertical lines indicate absence of beds in the section.

The name Trenton was first applied to the succession of Middle Ordovician limestone beds that are exposed in the gorge of West Canada Creek, at Trenton Falls, Oneida County, New York, by Vanuxem.[3] Conrad earlier probably intended to include the overlying Utica shale as well as the limestones exposed at Trenton Falls in his Trenton Falls group when he referred to the "Blue fetid limestones and shales of Trenton Falls."[4] In the years that have followed the various members occurring in the vicinity of Trenton Falls have been differentiated and correlated with rocks of similar age in other areas and the term Trenton has been expanded to group rank.

[3] Lardner Vanuxem, "Second Annual Report of so Much of the Third District of the State of New York as Related to Objects of Immediate Utility," *State of New York, Assembly No. 200* (1838), p. 255.

[4] T. A. Conrad, "First Annual Report on the Geological Survey of the Third District of the State of New York," *New York Geol. Survey 1st Ann. Rept.* (1837), pp. 155–86.

On the chart shown in Figure 2, following Kay, the Holland Patent black shale has been included in the Trenton group.[5] Ruedemann has shown that the 300–400 feet of black shale that overlie the Trenton limestone at Holland Patent, Oneida County, New York, constitute the upper division of the Utica shale as developed in the type area.[6] He correlates the Collingwood and Gloucester shales of Ontario with the Holland Patent.[7] Ruedemann considers the Utica shale to constitute an independent basal division of the Cincinnatian which is older than the Eden of the Cincinnati region and is represented by a hiatus in that area.[8] He includes the Cobourg in this division. Parks, on the other hand correlates the Gloucester of Ontario with the Whetstone Gulf or Lower Lorraine of New York, as defined by Ruedemann, and draws the line between the Middle and Upper Ordovician at its base.[9]

In central Pennsylvania, Kay has separated the 400 feet of black shale at the base of the Reedsville shale under the name Antes shale and has correlated this shale with the Holland Patent of New York on lithological and faunal grounds. He includes this shale in the Trenton group.[10]

In the Upper Mississippi Valley the Dubuque formation was considered to constitute the upper member of the Galena group and was correlated with the Collingwood of Ontario by Kay in 1935.[11] Stauffer and Thiel, however, regard the Dubuque in Minnesota[12] to be part of the Maquoketa formation of the late Upper Ordovician. Schuchert also considered the Stewartville formation, which underlies the Dubuque, to be late Upper Ordovician in age.[13]

SUBSURFACE SECTIONS

Six well-sample records have been selected to show the lithologic nature of the Trenton and sub-Trenton formations across the northern part of the Appalachian basin along a section extending from northwestern Ohio to south-central New York south of lakes Erie and Ontario.

The well sections start with the top of the Trenton limestone. The black

[5] G. Marshall Kay, "Stratigraphy of the Trenton Group," *Bull. Geol. Soc. America*, Vol. 48 (1937), p. 286.

[6] Rudolf Ruedemann, "The Utica and Lorraine Formations of New York," *New York State Mus. Bull. 258* (1925), pp. 33–39.

[7] *Ibid.*, pp. 62–64.

[8] *Ibid.*, pp. 147–49.

[9] W. A. Parks, "Faunas and Stratigraphy of the Ordovician Black Shales and Related Rocks in Southern Ontario," *Trans. Royal Soc. Canada*, 3d Ser., Sec. 4 (1928), pp. 59–60.

[10] G. Marshall Kay, "Middle Ordovician of Central Pennsylvania," *Jour. Geol.*, Vol. 52 (1944), p. 114.

[11] G. Marshall Kay, "Ordovician Stewartville-Dubuque Problems," *Jour. Geol.*, Vol. 43 (1935), pp. 561–90.

[12] Clinton R. Stauffer and George A. Thiel, "The Paleozoic and Related Rocks of Southeastern Minnesota," *Minnesota Geol. Survey Bull. 29* (1941), p. 90.

[13] Charles Schuchert, *Stratigraphy of the Eastern and Central United States* (1943), p. 726.

shales which overlie the limestone over much of the northern Appalachian basin have not been included. The black shales lose their dark color gradually as they pass upward into gray shales and, in most instances, it is difficult, if not impossible, to select a definite horizon where the change occurs. As has already been pointed out, there is not yet unanimous agreement among paleontologists and stratigraphers as to just where in the succession of dark shales the line between the Middle and the Upper Ordovician should be drawn on the outcrops, even where fossil evidence is available. The black Utica shales represent a facies of sedimentation during late Middle Ordovician and early Upper Ordovician time and not a time division. The top of the limestone, which is called the top of the Trenton by the drillers, therefore has been called the top of the Middle Ordovician or Champlainian series in the well-sample records with the realization that the horizon selected does not necessarily represent a surface of time equivalence over the whole northern Appalachian basin. Where drillers' logs have to be utilized in connection with subsurface studies, it is the only horizon available.

The six wells for which the records are given are designated as 1, 5, 10, 12, 13, and 20 on the map shown in Figure 1. The records follow.

NO. 1

OHIO OIL COMPANY'S LOUIS BARLAGE WELL NO. 1

Sec. 29, Liberty Township, Putnam County, Ohio. Ottawa Quadrangle, 0.8 mile N. of 41°5′ N. Lat. and 0.4 mile W. of 84°5′ W. Long. Completed, March 21, 1944. Showing of oil at 1,456–1,462 feet in Trenton; hole full of salt water at 2,100 feet and salt water at 2,424 feet in Trempealeau. Elevation, 740 feet above sea-level.

Thickness (Feet)	*Description of Strata*	*Depth (Feet)*
	MIDDLE ORDOVICIAN OR CHAMPLAINIAN SERIES, 598 FEET	
	Top of Trenton limestone	1,432
54	Limestone, fine, crystalline, light brownish gray, dolomitic. Showing of oil at 1,456–1462	1,486
39	Dolomite, very fine, crystalline, light brownish gray	1,525
9	Limestone, very fine, dark grayish brown, somewhat argillaceous, containing fragments of shells, with a little interbedded dark gray, slightly calcareous shale	1,534
46	Limestone, very fine, light grayish to dark grayish brown, containing fragments of shells	1,580
24	Limestone, very fine, grayish to very dark grayish brown, somewhat argillaceous and magnesian, containing abundant fragments of shells, including bryozoans, and a little light gray chert	1,604
21	Limestone, very fine, mottled light to dark brownish gray, containing abundant fragments of shells, with a very little interbedded light greenish gray, calcareous shale	1,625
29	Limestone, very fine, in part crystalline, mottled light to dark brownish gray, somewhat argillaceous, containing fragments of shells, with a little interbedded light gray bentonite	1,654
16	Limestone, very fine, light grayish to grayish brown, somewhat argillaceous, containing fragments of shells and a little light bluish to dark brownish gray chert. 7-inch casing set at 1,670 feet	1,670
24	Limestone, very fine, light grayish brown	1,694
46	Limestone, lithographic, light brownish gray	1,740
10	Limestone, very fine, brownish gray	1,750
95	Limestone, lithographic, light gray to light grayish brown	1,845

Thickness (Feet)	Description of Strata	Depth (Feet)
10	Limestone, very fine, grayish to dark grayish brown	1,855
65	Limestone, very fine, light brownish gray, somewhat magnesian	1,920
80	Limestone, lithographic, brownish gray, somewhat argillaceous	2,000
15	Limestone, very fine, light brownish gray	2,015
15	Limestone, lithographic, brownish gray	2,030
	LOWER ORDOVICIAN OR CANADIAN SERIES, 33 FEET	
	ONEOTA DOLOMITE, 33 FEET	
23	Dolomite, very fine, crystalline, very light brownish gray	2,053
10	Shale, light greenish gray, somewhat dolomitic, with considerable interbedded light greenish gray, dolomitic siltstone	2,063
	UPPER CAMBRIAN SERIES, 1,314 FEET	
	TREMPEALEAU FORMATION, 502 FEET	
35	Dolomite, very fine, very light brownish gray	2,098
254	Dolomite, very fine, crystalline, very light to light brownish gray. Hole full of water at 2,100 feet	2,352
31	Dolomite, very fine, crystalline, brownish gray	2,383
13	Dolomite, very fine, crystalline, dark grayish brown	2,396
44	Dolomite, very fine, crystalline, brownish gray, somewhat argillaceous. Water at 2,424 feet	2,440
12	Shale, gray, silty and somewhat dolomitic	2,452
43	Siltstone, brownish gray, dolomitic	2,495
42	Dolomite, very fine, crystalline, somewhat argillaceous and silty	2,537
28	Dolomite, very fine, crystalline, sandy, containing a little glauconite	2,565
	FRANCONIA SANDSTONE, 25 FEET	
25	Sandstone, fine- to medium-grained, brownish gray, dolomitic, containing a little glauconite, quartz grains angular to subangular	2,590
	DRESBACH SANDSTONE, 10 FEET	
10	Sandstone, fine- to medium-grained, brownish gray, somewhat dolomitic, quartz grains angular to subangular	2,600
	EAU CLAIRE SANDSTONE, 350 FEET	
22	Siltstone, light brownish gray, dolomitic, containing some glauconite, with considerable interbedded gray shale	2,622
18	Shale, gray, with a little interbedded purplish gray shale	2,640
20	Shale, gray, with considerable interbedded light brownish gray dolomitic siltstone, containing abundant glauconite	2,660
5	Siltstone, brownish and greenish gray, dolomitic, containing some glauconite, with some interbedded gray and greenish gray shale	2,665
5	Shale, dark purplish gray, with considerable interbedded greenish gray, dolomitic siltstone containing some glauconite	2,670
20	Sandstone, very fine-grained, gray, dolomitic, with some interbedded greenish gray shale. 5½-inch casing set at 2,677 feet	2,690
32	Siltstone, light gray to brownish and greenish gray, dolomitic, containing a little glauconite, with considerable interbedded gray shale	2,722
11	Sandstone, very fine-grained, reddish brown, somewhat dolomitic	2,733
19	Sandstone, fine- to medium-grained, brownish gray, dolomitic, containing some glauconite; quartz grains angular to subangular	2,752
87	Sandstone, fine-grained, light brownish gray, somewhat dolomitic, containing a little glauconite; quartz grains angular to subangular	2,839
44	Siltstone, brownish and purplish gray, somewhat dolomitic, containing considerable glauconite, with some interbedded purplish gray shale	2,883
17	Sandstone, very fine- to fine-grained, brownish gray, somewhat dolomitic; quartz grains angular to subangular	2,900

Thickness (Feet)	Description of Strata	Depth (Feet)
7	Sandstone, medium-grained, light gray, somewhat dolomitic; quartz grains subangular	2,907
43	Sandstone, fine-grained, light gray to light brownish gray, somewhat dolomitic; quartz grains subangular	2,950
	MOUNT SIMON SANDSTONE, 292 FEET	
8	Sandstone, medium- to coarse-grained, light gray; larger quartz grains subrounded	2,958
74	Sandstone, very fine-grained, light gray	3,032
25	Sandstone, fine-grained, light gray, almost white	3,057
25	Sandstone, fine- to medium-grained, light gray; larger quartz grains subrounded	3,082
10	Sandstone, coarse-grained, light gray; many of quartz grains subrounded	3,092
48	Sandstone, coarse- to very coarse-grained, light reddish gray; most of quartz grains subangular, a few rounded and frosted	3,140
79	Sandstone, medium- to coarse-grained, light reddish gray; many of larger quartz grains subrounded and frosted	3,219
23	Sandstone, fine-grained, light reddish gray; quartz grains subangular	3,242
	JACOBSVILLE SANDSTONE, 135 FEET	
58	Sandstone, fine-grained, grayish red, somewhat argillaceous, containing some pink orthoclase and a little muscovite	3,300
77	Arkose, grayish red, composed of quartz, some partly altered pink, orthoclase, and a little muscovite, all stained red by ferric oxide; quartz grains subangular to subrounded	3,377
	Total depth	3,377

NO. 5

OHIO OIL COMPANY'S S. V. KRAUSE WELL NO. 1

Tract 14, Ruggles Township, Ashland County, Ohio. New London Quadrangle, 1.19 miles N. of 41°00′ N. Lat. and 1.2 miles W. of 82°20′ W. Long. Completed, 1945. 260,000 cubic feet of gas and showing of oil at 4,420–4,434 feet and 40 bailers of salt water per day at 4,537–4,543 in Trempealeau; hole full of salt water at 4,683–4,692 in Dresbach; 30 bailers of salt water per day at 4,805–4,814 and hole full of salt water at 5,041–5,048 feet in Eau Claire. Elevation, 1,114 feet above sea-level.

Thickness (Feet)	Description of Strata	Depth (Feet)
	MIDDLE ORDOVICIAN OR CHAMPLAINIAN SERIES, 660 FEET	
	Top of Trenton limestone	3,758
5	Limestone, very fine, dense, gray to dark grayish brown, argillaceous and slightly magnesian, containing abundant fragments of shells	3,763
	Bottom of $6\frac{5}{8}$-inch casing	3,763
55	Limestone, very fine, crystalline, grayish brown, somewhat argillaceous and slightly magnesian, containing some light gray to brownish gray chert and abundant fragments of shells	3,818
35	Limestone, very fine, dense, brownish gray, argillaceous and slightly magnesian, containing fragments of shells and a little brownish gray chert	3,853
39	Limestone, very fine, dense, light brownish gray, argillaceous, containing fragments of shells, with some interbedded light gray bentonite	3,892
26	Limestone, very fine, dense, brownish gray, argillaceous, with some interbedded light gray bentonite	3,918
20	Limestone, very fine, dense, light brownish gray, somewhat argillaceous, containing a little light gray chert	3,938
28	Limestone, very fine, dense, light brownish gray, containing fragments of shells	3,966
22	Limestone, very fine, dense, brownish gray	3,988
74	Limestone, very fine, dense, light brownish gray, containing fragments of shells	4,062
58	Limestone, very fine, dense, grayish brown, containing fragments of shells	4,120

Thickness (Feet)	Description of Strata	Depth (Feet)
191	Limestone, very fine, dense, light brownish gray	4,311
16	Limestone, very fine, dense, light brownish gray with a little interbedded greenish gray, slightly calcareous shale	4,327
46	Limestone, very fine, dense, light brownish gray, somewhat argillaceous and magnesian	4,373
16	Limestone, very fine, dense, grayish brown, with some interbedded greenish gray, calcareous shale	4,389
25	Limestone, very fine, dense, grayish brown, with much interbedded grayish green, somewhat calcareous shale	4,414
4	Shale, grayish green	4,418
	UPPER CAMBRIAN SERIES, 833+FEET	
	TREMPEALEAU AND FRANCONIA FORMATIONS, 265 FEET	
22	Sandstone, very fine-grained, light buff, almost white, quartzose and dolomitic. 260,000 cubic feet gas per 24 hours I.O.F., with slight showing of oil at 4,420–4,434; salt water at 4,432 feet	4,440
16	Shale, gray, silty, with a great deal of interbedded light gray siltstone containing some muscovite	4,456
8	Siltstone, light brownish gray, dolomitic	4,464
8	Sandstone, very fine-grained, light buff, quartzose and dolomitic, with considerable interbedded greenish gray shale	4,472
101	Dolomite, very fine, crystalline, light buff, silty. 40 bailers salt water per day at 4,537–4,543 feet	4,573
14	Dolomite, very fine, crystalline, brownish gray, silty	4,587
7	Dolomite, very fine, crystalline, brownish gray, silty, containing minute grains of glauconite	4,594
54	Dolomite, very fine, crystalline, light grayish brown, containing some fine quartz grains, the larger of which are rounded and frosted	4,648
22	Dolomite, very fine, crystalline, light grayish brown, containing much fine-grained quartz sand, some of the larger grains of which are rounded and frosted	4,670
13	Dolomite, very fine, crystalline, light buff, containing some fine quartz grains, some of which are rounded and frosted	4,683
	DRESBACH SANDSTONE, 57 FEET	
7	Sandstone, fine- to medium-grained, light buff, quartzose and dolomitic, many of quartz grains rounded and frosted	4,690
13	Sandstone, medium-grained, light buff, quartzose and slightly dolomitic, with larger quartz grains rounded and frosted. Hole full of salt water at 4,683–4,692	4,703
37	Sandstone, very fine- to fine-grained, light buff, quartzose and somewhat dolomitic, with some of larger quartz grains rounded and frosted	4,740
	EAU CLAIRE SANDSTONE, 385 FEET	
6	Sandstone, very fine- to fine-grained, light buff, quartzose, with considerable interbedded dark brownish gray, somewhat dolomitic siltstone	4,746
16	Sandstone, very fine- to fine-grained, brownish gray, quartzose and dolomitic, with some quartz grains rounded and frosted	4,762
10	Sandstone, very fine- to fine-grained, light buff, quartzose and somewhat dolomitic, with some quartz grains rounded and frosted	4,772
22	Sandstone, very fine- to fine-grained, light buff, quartzose and dolomitic, with some of larger quartz grains rounded and frosted, with considerable interbedded dark brownish gray dolomitic siltstone containing a little glauconite	4,794
	Bottom of 5½-inch casing	4,780
23	Sandstone, very fine- to fine-grained, light grayish brown, quartzose and dolomitic, with some of quartz grains rounded and frosted. 30 bailers salt water per day at 4,805–4,814 feet	4,817
44	Dolomite, very fine, crystalline, light buff, containing a few very fine to fine quartz grains, some of the larger of which are rounded and frosted	4,861
40	Dolomite, very fine, crystalline, light grayish brown, containing some very fine to fine quartz sand, some of quartz grains rounded and frosted	4,901
132	Dolomite, very fine, crystalline, light brownish gray, sandy; quartz grains very fine to fine, some rounded and frosted	5,033

Thickness (Feet)	Description of Strata	Depth (Feet)
52	Dolomite, very fine, crystalline, dark grayish brown, sandy; quartz grains very fine to fine, some rounded and frosted, many possess secondary crystal facets. Hole full of salt water at 5,041–5,048	5,085
14	Sandstone, fine-grained, brownish gray, quartzose and dolomitic, some of quartz grains rounded and frosted, many possess secondary crystal facets	5,099
7	Dolomite, very fine, crystalline, grayish brown, sandy	5,106
8	Sandstone, fine- to medium-grained, dark brownish gray, quartzose and somewhat dolomitic, some of quartz grains rounded and frosted, many possess secondary crystal facets	5,114
11	Sandstone, fine- to medium-grained, brownish gray, quartzose and dolomitic, some of quartz grains rounded and frosted, many possess secondary crystal facets	5,125
	MOUNT SIMON SANDSTONE, 126+ FEET	
11	Sandstone, fine- to medium-grained, light gray, quartzose, some of quartz grains rounded and frosted, many possess secondary crystal facets	5,136
5	Sandstone, fine-grained, light gray, quartzose and somewhat dolomitic, some of quartz grains rounded and frosted, many possess secondary crystal facets	5,141
33	Sandstone, fine- to medium-grained, light gray, quartzose, some of grains rounded and frosted, many possess secondary crystal facets	5,174
77	Sandstone, medium-grained, light gray, quartzose, with many grains rounded and frosted	5,251
	Total depth	5,251

NO. 10

OHIO OIL COMPANY'S JAY CHILDS WELL NO. 1

Springfield Township, Erie County, Pennsylvania. Girard Quadrangle, 2.23 miles S. of 42°00′ N. Lat. and 0.95 mile W. of 80°30 W. Long. Completed, March 30, 1941. Showing of gas and one barrel of oil per day at 4,441 feet and a little salt water at 4,460 feet in Trenton; slight showing of gas and oil and a little salt water, 5,182–5,188 feet, more salt water, 5,188–5,191 feet, rose 3,000 feet, in Dresbach. Elevation: 638 feet above sea-level.

Thickness (Feet)	Description of Strata	Depth (Feet)
	MIDDLE ORDOVICIAN OR CHAMPLAINIAN SERIES, 742 FEET	
	Top of Trenton limestone	4,437
25	Limestone, very fine, crystalline, light grayish brown, slightly magnesian. Showing of oil, about one barrel per day, at 4,441 and a little salt water at 4,460 feet	4,462
17	Limestone, very fine, dense, very dark grayish brown, somewhat argillaceous, with considerable interbedded very fine, crystalline, light grayish brown limestone containing fragments of shells	4,479
45	Limestone, very fine, dense, very dark brownish gray, somewhat argillaceous, containing fragments of shells	4,524
24	Limestone, very fine, dense, very dark brownish gray, argillaceous, containing fragments of shells	4,548
42	Limestone, very fine, dense, light to dark brownish gray, argillaceous, containing fragments of shells	4,590
17	Limestone, very fine, dense, very dark brownish gray, argillaceous	4,607
10	Shale, grayish black, calcareous, with considerable interbedded, very fine, dense, very dark brownish gray, argillaceous limestone	4,617
59	Limestone, very fine, dense, very dark, brownish gray, argillaceous, containing fragments of shells	4,676
46	Limestone, very fine, dense, very dark brownish gray, somewhat argillaceous, containing fragments of shells	4,722
40	Limestone, very fine, crystalline, grayish brown, containing abundant fragments of shells, with some interbedded very fine, dense, very dark brownish gray, somewhat argillaceous limestone	4,762

Thickness (Feet)	Description of Strata	Depth (Feet)
11	Limestone, very fine, dense, dark grayish brown, argillaceous, containing fragments of shells and a little brownish gray chert	4,773
	Top of bentonite zone	4,773
7	Limestone, very fine, dense, dark grayish brown, argillaceous, containing fragments of shells and considerable brownish gray chert, with some interbedded light gray bentonite	4,780
11	Limestone, very fine, dense, dark grayish brown, argillaceous, containing fragments of shells, with considerable interbedded light gray bentonite	4,791
11	Limestone, very fine, dense, grayish brown, argillaceous, with a little interbedded light gray bentonite	4,802
11	Bentonite, light gray, with a little interbedded very fine, dense, grayish brown, argillaceous limestone	4,813
7	Bentonite, light gray, with some interbedded, very fine, dense, grayish brown, argillaceous limestone	4,820
10	Limestone, very fine, dense, grayish brown, argillaceous, with considerable interbedded light gray bentonite; limestone contains some brownish gray chert	4,830
	Bottom of bentonite zone	4,830
150	Limestone, very fine, dense, grayish brown; contains a little brownish gray chert and occasional fragments of shells	4,980
13	Limestone, very fine, crystalline, grayish brown, somewhat magnesian; contains minutely porous light gray chert	4,993
34	Limestone, very fine, dense, grayish brown; contains fragments of shells	5,027
50	Limestone, very fine, dense, dark grayish brown; contains fragments of shells	5,077
13	Limestone, very fine, dense, dark brownish gray, somewhat argillaceous	5,090
13	Limestone, very fine, dense, gray to dark greenish gray, argillaceous	5,103
7	Limestone, very fine, dense, dark brownish gray, argillaceous	5,110
27	Limestone, very fine, dense, grayish brown; contains fragments of shells	5,137
13	Limestone, very fine, dense, dark grayish brown	5,150
6	Limestone, very fine, crystalline, dark grayish brown, sandy, and argillaceous; fine quartz grains mostly subangular, but some are subrounded to rounded and frosted	5,156
5	Limestone, very fine, dense, dark gray, shaly	5,161
4	Limestone, very fine, crystalline, dark grayish brown, somewhat argillaceous	5,165
6	Limestone, very fine, dense, very dark brownish gray, somewhat argillaceous and magnesian	5,171
8	Shale, gray	5,179
	UPPER CAMBRIAN SERIES, 12+ FEET	
	DRESBACH SANDSTONE, 12+ FEET	
5	Sandstone, fine- to medium-grained, light gray to white, somewhat dolomitic; quartz grains subrounded to rounded and frosted	5,184
7	Sandstone, fine- to medium-grained, light gray to white; quartz grains subrounded to rounded and frosted. Slight showing of gas and oil and a little salt water, 5,185–5,188 feet; more salt water, 5,188–5,191 feet, rose 3,000 feet in hole	5,191
	Total depth	5,191

NO. 12

K. R. Wilson's Arcade Well No. 1

Town of Arcade, Wyoming County, New York. Arcade Quadrangle, 2.11 miles N. of 42°11′ N. Lat. and 0.35 mile W. of 78°25′ W. Long. Completed, August 21, 1946. Showing of oil and a little gas at 5,994 feet and showing of gas at 6,030 feet in Black River; 25,000 cubic feet of gas at 6,182 feet in Tribes Hill; salt water, 6,375–6,395 feet in Theresa; salt water at 7,040 feet in Potsdam. Elevation: 1,483 feet above sea-level.

Thickness (Feet)	Description of Strata	Depth (Feet)
	MIDDLE ORDOVICIAN OR CHAMPLAINIAN SERIES, 767 FEET	
	Top of Trenton limestone	5,342
31	Limestone, very fine, dense, dark brownish gray, argillaceous, containing fragments of shells, with considerable interbedded dark gray shale	5,373

Thickness (Feet)	Description of Strata	Depth (Feet)
20	Limestone, very fine, dense, dark brownish gray, argillaceous, containing fragments of shells	5,393
55	Limestone, very fine, crystalline to dense, mottled light and dark brownish gray, containing abundant fragments of shells	5,448
208	Limestone, dark gray, shaly, containing fragments of shells	5,656
63	Limestone, very fine, dense, dark brownish gray, argillaceous, containing fragments of shells, with some interbedded very dark gray, calcareous shale	5,719
118	Limestone, very fine, crystalline, brownish gray, containing fragments of shells, with considerable interbedded dark brownish gray shaly limestone	5,837
16	Limestone, very fine, dense, dark brownish gray, somewhat argillaceous, containing fragments of shells	5,863
39	Limestone, very fine, dense, brownish gray, somewhat argillaceous, with a little interbedded light gray bentonite	5,892
72	Limestone, very fine, dense, brownish gray, somewhat argillaceous	5,964
16	Limestone, very fine, dense, brownish gray, somewhat argillaceous, with a little interbedded slightly calcareous black shale	5,980
8	Limestone, very fine, dense, brownish to dark brownish gray, somewhat argillaceous	5,988
36	Limestone, very fine, dense, brownish gray, argillaceous, with some interbedded light greenish gray bentonite	6,024
23	Limestone, very fine, crystalline, brownish gray, dolomitic, with a great deal of interbedded, very fine, dense, brownish gray, somewhat argillaceous limestone. Showing of gas at 6,030 feet	6,047
15	Limestone, very fine, crystalline, brownish gray	6,062
11	Limestone, very fine, dense, light brownish to brownish gray, slightly magnesian	6,073
19	Limestone, very fine, dense to crystalline, light brownish to brownish gray, somewhat argillaceous and slightly magnesian	6,092
17	Limestone, very fine, dense, light gray, somewhat argillaceous and slightly magnesian	6,109
	LOWER ORDOVICIAN OR CANADIAN SERIES, 86 FEET	
	TRIBES HILL LIMESTONE, 86 FEET	
12	Limestone, very fine, dense, brownish gray, somewhat magnesian	6,121
7	Limestone, fine, oölitic, argillaceous, silty and slightly magnesian; oölites, dark brownish gray and matrix, light gray	6,128
5	Limestone, very fine, dense, dark brownish gray, argillaceous	6,133
8	Limestone, fine, oölitic, argillaceous, silty and slightly magnesian; oölites, dark brownish gray and matrix, light gray	6,141
31	Limestone, very fine, crystalline, light gray, somewhat argillaceous, silty and magnesian, with a few fine subrounded and frosted quartz grains in upper part	6,172
17	Limestone, very fine, dense to very fine, crystalline, light brownish gray, argillaceous, silty and somewhat magnesian. 25,000 cubic feet of gas at 6,182	6,189
6	Limestone, light gray, shaly, silty and somewhat magnesian, containing a few fine- to medium-rounded and frosted quartz grains	6,195
	UPPER CAMBRIAN SERIES, 949+ FEET	
	LITTLE FALLS DOLOMITE, 130 FEET	
5	Dolomite, fine, crystalline, light brownish gray containing considerable very fine to fine quartz sand, the larger grains of which are subrounded and frosted	6,200
57	Dolomite, fine, crystalline, light brownish gray	6,257
32	Dolomite, fine, crystalline, light gray	6,289
10	Dolomite, fine, crystalline, light gray, containing considerable very fine to fine, angular quartz sand, with a few of the larger grains subrounded and frosted	6,299
12	Dolomite, fine, crystalline, light gray, containing much very fine to fine poorly sorted, subangular quartz sand, with a few rounded and frosted grains to 0.5 millimeter in diameter	6,311
5	Sandstone, fine- to medium-grained, light brownish gray, quartzose and dolomitic with some of larger quartz grains rounded and frosted	6,316
9	Dolomite, very fine, crystalline, light brownish gray, containing a great deal of very fine to fine, poorly sorted, subangular quartz sand, with a few of larger grains rounded and frosted	6,325

Thickness (Feet)	Description of Strata	Depth (Feet)
	THERESA FORMATION, 643 FEET	
10	Sandstone, fine- to medium-grained, light brownish gray, quartzose and somewhat dolomitic, with most of quartz grains subangular, some larger grains, rounded and frosted	6,335
7	Sandstone, fine- to medium-grained, light brownish gray, quartzose and slightly dolomitic, with most of quartz grains subangular, some larger grains, rounded and frosted	6,342
26	Sandstone, fine-grained, light gray to light brownish gray, subangular, quartzose, with a few larger grains rounded and frosted	6,368
23	Sandstone, medium-grained, light brownish gray, subangular, quartzose, with some larger grains rounded and frosted. Salt water at 6,375–6,395	6,391
43	Sandstone, fine- to medium-grained, poorly sorted light gray to light brownish gray, subangular, quartzose, with some larger grains rounded and frosted	6,434
32	Sandstone, fine-grained, light brownish gray, subangular, quartzose, with a few larger grains rounded and frosted	6,466
4	Dolomite, very fine, dense, light brownish gray, argillaceous and silty	6,470
7	Dolomite, very fine, crystalline, light gray, containing considerable fine- to medium-grained, poorly sorted quartz sand, with many rounded and frosted grains	6,477
13	Sandstone, medium-grained, light gray, quartzose and somewhat dolomitic, containing many rounded and frosted grains	6,490
24	Sandstone, fine-grained, light gray, quartzose and somewhat dolomitic, subangular with few rounded and frosted grains	6,514
52	Dolomite, very fine, crystalline, light gray to light brownish gray, containing some very fine to fine subangular quartz sand, with a few grains rounded and frosted	6,566
4	Sandstone, very fine-grained, light brownish gray, quartzose and somewhat dolomitic, angular	6,570
18	Sandstone, very fine-grained, light brownish gray, quartzose and somewhat dolomitic, subangular, with a few of larger grains rounded and frosted	6,588
13	Dolomite, very fine, crystalline, light brownish gray, containing some fine, subangular quartz sand, with a few of larger grains rounded and frosted	6,601
5	Sandstone, fine-grained, light brownish gray, quartzose and somewhat dolomitic, subangular, with a few larger grains rounded and frosted	6,606
10	Dolomite, very fine, crystalline, light brownish gray, containing some very fine to fine subangular quartz sand with some larger grains rounded and frosted	6,616
10	Dolomite, very fine, crystalline, light brownish gray, containing some very fine to fine subangular quartz sand with a few grains rounded and frosted and some chalk-textured chert	6,626
15	Dolomite, very fine, crystalline, light brownish gray, containing some very fine, subangular quartz sand	6,641
47	Dolomite, very fine, crystalline, light brownish gray, containing considerable very fine, subangular quartz sand	6,688
33	Dolomite, very fine to fine, crystalline, brownish gray, containing some very fine to fine angular quartz sand with a few larger grains rounded and frosted	6,721
34	Dolomite, very fine, crystalline, brownish gray, containing considerable very fine, angular quartz sand and silt and some dark gray clay	6,755
5	Dolomite, very fine, crystalline, brownish gray, containing some very fine, angular quartz sand and silt and some dark gray clay	6,760
70	No samples	6,830
24	Dolomite, very fine, crystalline, dark brownish gray, containing much very fine, subangular quartz sand and some dark gray clay	6,854
25	Sandstone, fine-grained, light brownish gray, subangular quartzose and somewhat dolomitic	6,897
5	Dolomite, very fine, crystalline, light brownish gray, containing some very fine subangular quartz sand and gray clay	6,884
2	Sandstone, fine- to medium-grained, light brownish gray, quartzose and slightly dolomitic, subangular, with some larger grains rounded and frosted	6,886
11	Sandstone, very fine- to fine-grained, light brownish gray, quartzose and slightly dolomitic	6,897
3	Dolomite, very fine, crystalline, brownish gray, containing considerable very fine to fine subangular quartz sand	6,900

Thickness (Feet)	Description of Strata	Depth (Feet)
20	Dolomite, very fine, crystalline, dark brownish gray, containing some very fine to fine subangular quartz sand	6,920
48	Dolomite, very fine, crystalline, brownish gray, containing considerable very fine to fine subangular quartz sand with few rounded and frosted grains	6,968
	POTSDAM SANDSTONE, 176 FEET	
32	Sandstone, very fine- to fine-grained, light brownish gray, quartzose and somewhat dolomitic, subangular with few rounded and frosted grains	7,000
15	Sandstone, very fine- to fine-grained, light brownish gray, quartzose and dolomitic, subangular, with few rounded and frosted grains	7,015
12	Dolomite, very fine, crystalline, dark brownish gray, containing considerable very fine to fine, subangular quartz sand with few rounded and frosted grains	7,027
38	Sandstone, fine-grained, light gray, quartzose and slightly dolomitic, subangular, with few rounded and frosted grains. Salt water at 7,040 feet, rose 5,500 feet	7,065
30	Sandstone, very fine- to fine-grained, light brownish gray, slightly calcareous; quartz grains, mostly subangular	7,095
8	Sandstone, very fine- to fine-grained, light brownish gray, somewhat dolomitic; quartz grains, subangular; a little interbedded light greenish gray, silty, and micaceous shale	7,103
6	Sandstone, very fine- to fine-grained, light brownish gray; quartz grains, subangular	7,109
15	Sandstone, very fine-grained, light brownish gray, with a little interbedded dark gray shale	7,124
9	Sandstone, very fine-grained, light brownish gray, slightly dolomitic and containing a little muscovite	7,133
11	Sandstone, very fine-grained, light pink, containing a few orthoclase grains and a little muscovite; quartz grains, subangular	7,144
	Total depth	7,144

NO. 13

RESERVE OIL COMPANY'S J. C. MAHANEY WELL NO. 1

Town of Ledyard, Cayuga County, New York. Genoa Quadrangle, 1.3 miles N. of 42°40′ N. Lat. and 1.2 miles E. of 76°40′ W. Long. Completed, May, 1931. Elevation: 824 feet above sea-level.

Thickness (Feet)	Description of Strata	Depth (Feet)
	MIDDLE ORDOVICIAN OR CHAMPLAINIAN SERIES, 833 FEET	
	Top of Trenton limestone	5,054
13	Limestone, very fine, crystalline, mottled light and dark brownish gray, somewhat argillaceous, containing fragments of shells	5,067
49	Limestone, very fine, very dark gray, argillaceous, containing fragments of shells	5,116
38	Limestone, very fine, very dark gray, shaly, containing fragments of shells, with some interbedded light gray bentonite	5,154
16	Limestone, very fine, very dark gray, argillaceous, containing fragments of shells	5,170
15	Limestone, very fine, very dark gray, shaly, containing fragments of shells including crinoid stems, with considerable interbedded light gray bentonite	5,185
10	Limestone, very fine, very dark gray, shaly, with a little interbedded light gray bentonite	5,195
10	Limestone, very fine, very dark gray, shaly, containing fragments, of shells	5,205
29	Limestone, very fine, very dark gray, shaly, with some interbedded light gray bentonite	5,234
31	Limestone, very fine, very dark gray, shaly, with little interbedded light gray bentonite	5,265
8	Shale, very dark gray, very calcareous	5,273
15	Limestone, very fine, very dark gray, shaly	5,288
41	Shale, very dark gray, very calcareous	5,329
78	Limestone, very fine, very dark gray, argillaceous, containing fragments of shells	5,407
26	No samples	5,433

Thickness (Feet)	Description of Strata	Depth (Feet)
12	Limestone, very fine, very dark gray, shaly	5,445
81	Limestone, very fine, very dark gray, shaly, with some interbedded, very fine, crystalline, brownish gray limestone containing fragments of shells	5,526
38	Limestone, very fine, crystalline, brownish gray, containing fragments of shells, with a great deal of interbedded, very dark gray, shaly limestone	5,564
32	Limestone, very fine, very dark gray, shaly, with some interbedded, very fine, crystalline, dark brownish gray limestone, containing fragments of shells	5,596
63	Limestone, very fine, very dark gray, shaly	5,659
14	No samples	5,673
15	Shale, very dark gray, calcareous, with some interbedded very fine, dark gray argillaceous limestone and a little light gray bentonite	5,688
82	Limestone, lithographic, dark brownish gray, slightly argillaceous	5,770
12	Limestone, lithographic, light to dark brownish gray	5,872
71	Limestone, very fine, dark brownish gray, somewhat argillaceous and magnesian	5,853
34	Limestone, very fine, very dark brownish gray, somewhat argillaceous and magnesian	5,887
	LOWER ORDOVICIAN OR CANADIAN SERIES, 211 FEET	
	TRIBES HILL LIMESTONE, 211 FEET	
35	Limestone, very fine, light to dark brownish gray, argillaceous and somewhat magnesian	5,922
84	Limestone, very fine, light gray, argillaceous, containing a few fine- to medium-sized subrounded and frosted quartz grains	6,006
6	Limestone, very fine, light gray, argillaceous and somewhat magnesian	6,012
6	Limestone, very fine, light gray, sandy and somewhat magnesian; quartz grains very fine to fine, with some larger grains subrounded and frosted	6,018
6	Limestone, very fine, light gray, silty, argillaceous and somewhat magnesian, containing a few rounded and frosted quartz grains	6,024
37	Limestone, very fine, light gray to gray, argillaceous and somewhat magnesian	6,061
16	Limestone, very fine, crystalline, light gray, dolomitic	6,077
21	Limestone, very fine, crystalline, light gray, dolomitic and argillaceous	6,098
	UPPER CAMBRIAN SERIES, 68 FEET	
	LITTLE FALLS DOLOMITE, 68 FEET	
10	Dolomite, very fine to fine, crystalline, light gray	6,108
31	Dolomite, very fine, crystalline, light gray, somewhat silty, containing an occasional fine- to medium-sized subrounded and frosted quartz grain	6,139
12	Dolomite, fine, crystalline, light gray, somewhat silty	6,151
5	Dolomite, very fine, crystalline, light gray, silty and sandy, containing some fine to medium-sized subrounded and frosted quartz grains	6,156
10	No samples	6,166
	Total depth	6,166

NO. 20

MANUFACTURERS LIGHT AND HEAT COMPANY'S JESSIE G. HOCKENBERRY WELL NO. 1

Mercer Township, Butler County, Pennsylvania. Mercer Quadrangle, 1.61 miles N. of 41°45′ N. Lat. and 2.13 miles W. of 80°00′ W. Long. Completed, November 10, 1944. Showing of gas, 9,505–9,510 feet in Black River, good showing of gas, 9,746–9,771 feet in Mines, acidized without results; one bailer salt water per hour at 10,092 feet in Gatesburg. Elevation: 1,306 feet above sea-level.

Thickness (Feet)	Description of Strata	Depth (Feet)
	MIDDLE ORDOVICIAN OR CHAMPLAINIAN SERIES, 741 FEET	
	Top of Trenton limestone	8,812
22	Limestone, very fine, dense, very dark gray, almost black, slightly magnesian, containing abundant fragments of shells, with some interbedded grayish black, calcareous shale	8,834

Thickness (Feet)	Description of Strata	Depth (Feet)
14	Limestone, very fine, crystalline, dark brownish gray, somewhat silty and argillaceous and slightly magnesian, containing abundant fragments, of shells and a little black dense chert, with some interbedded grayish black, calcareous shale	8,848
18	Limestone, very fine, crystalline, dark brownish gray, silty and argillaceous, slightly magnesian, containing abundant fragments of shells and a little brownish gray dense dense chert, with some interbedded dark gray, somewhat calcareous shale	8,866
12	Limestone, dark gray, shaly, with considerable interbedded, very fine, crystalline, dark brownish gray, argillaceous limestone, containing abundant fragments of shells	8,878
14	Limestone, very fine, crystalline, brownish gray, argillaceous, with considerable interbedded, dark gray, shaly limestone	8,892
19	Limestone, dark to very dark gray, shaly, with considerable interbedded, very fine, crystalline, dark brownish gray, argillaceous limestone, containing abundant fragments of shells	8,911
39	Limestone, very fine, dense, dark brownish gray, argillaceous and slightly magnesian, containing abundant fragments of shells, with some interbedded, very dark gray, somewhat calcareous shale	8,950
32	Limestone, very fine, dense, dark to very dark brownish gray, argillaceous and slightly magnesian, containing fragments of shells	8,982
12	Shale, very dark gray, calcareous, with some interbedded, very fine, dense, dark brownish gray, argillaceous and slightly magnesian limestone and a very little light gray bentonite	8,994
17	Limestone, very fine, dense, dark brownish gray, somewhat argillaceous and slightly magnesian, containing abundant fragments of shells	9,011
9	Limestone, very fine, dense, very dark brownish gray, somewhat argillaceous and slightly magnesian, containing fragments of shells, with a little interbedded light gray bentonite	9,020
14	Limestone, very fine, dense, very dark brownish gray, somewhat argillaceous, containing fragments of shells	9,034
16	Limestone, very fine, dense, light gray, to gray, slightly magnesian	9,050
55	Limestone, very fine, dense, dark brownish gray, somewhat argillaceous and slightly magnesian	9,105
21	Limestone, very fine, dense, light gray to brownish gray, somewhat argillaceous and slightly magnesian	9,126
83	Limestone, very fine, dense, dark brownish gray, slightly magnesian	9,209
16	Limestone, very fine, crystalline, light to dark brownish gray, slightly magnesian	9,225
46	Limestone, very fine, dense, brownish to dark brownish gray, slightly magnesian, containing fragments of shells	9,271
117	Limestone, very fine, dense, dark to very dark brownish gray, slightly argillaceous and magnesian	9,388
40	Limestone, very fine, dense, gray, argillaceous, with some interbedded dark brownish gray calcareous shale	9,428
11	Limestone, very fine, dense, brownish to dark brownish gray, somewhat argillaceous and magnesian	9,439
11	Limestone, very fine, crystalline, brownish gray, somewhat magnesian	9,450
48	Limestone, very fine, dense, dark to very dark brownish gray, argillaceous and somewhat magnesian	9,498
7	Limestone, very fine, oölitic, dark brownish gray, argillaceous and somewhat magnesian	9,505
30	Limestone, very fine, dense, dark brownish gray, argillaceous and somewhat magnesian, with some interbedded gray to dark gray, somewhat calcareous shale. Show of gas, 9,505–9,510	9,535
13	Limestone, very fine, dense, light gray to gray, argillaceous and dolomitic	9,548
5	Shale, very dark brownish gray, calcareous, with some interbedded, very fine, dense, gray, argillaceous and dolomitic limestone	9,553
	LOWER ORDOVICIAN OR CANADIAN SERIES, 187 FEET	
	LARKE DOLOMITE, 187 FEET	
5	Dolomite, fine, crystalline, light brownish gray, containing some light gray, dense chert	9,558

Thickness (Feet)	Description of Strata	Depth (Feet)
2	Dolomite, fine, crystalline, light brownish gray, containing some light gray, dense chert, and a few subrounded to rounded, frosted quartz grains	9,560
20	Dolomite, fine to medium, crystalline, light brownish gray	9,580
14	Dolomite, fine to medium, crystalline, light brownish gray containing a little light gray, dense chert	9,594
68	Dolomite, fine to medium, crystalline, light gray to light brownish gray	9,662
78	Dolomite, fine, crystalline, light brownish gray, containing small drusy cavities lined with minute dolomite crystals	9,740
	UPPER CAMBRIAN SERIES, 356 FEET	
	MINES DOLOMITE, 308 FEET	
6	Dolomite, fine crystalline, mottled light brownish gray and black	9,746
13	Dolomite, very fine to fine, crystalline, light brownish gray, slightly silty	9,759
24	Dolomite, very fine to fine, crystalline, light gray, containing a few rounded and frosted quartz grains. Showing of gas, 9,746–9,771, acidized without results	9,783
32	Dolomite, very fine, crystalline, light brownish gray, somewhat siliceous, containing some rounded and frosted quartz grains	9,815
56	Dolomite, fine, crystalline, light brownish gray, containing a little fine quartz silt and sand; larger quartz grains rounded and frosted	9,871
4	Dolomite, fine, crystalline, brownish gray, somewhat siliceous, containing some very fine to fine quartz grains; larger grains rounded and frosted	9,875
15	Dolomite, fine, crystalline, brownish gray, containing considerable light gray oolitic chert, with individual siliceous oölites up to 1½ millimeters in diameter	9,890
16	Dolomite, very fine to fine, crystalline, brownish gray, slightly argillaceous, containing some quartz silt and very fine sand, with most larger quartz grains rounded and frosted	9,906
57	Dolomite, very fine, crystalline, light brownish gray, containing a little white chert and some quartz silt and fine sand, with larger quartz grains rounded and frosted	9,963
85	Dolomite, fine to medium, crystalline, light brownish gray	10,048
	GATESBURG FORMATION, 48 FEET	
21	Limestone, fine crystalline, mottled light and dark gray, dolomitic, silty and sandy, with larger quartz grains rounded and frosted	10,069
5	Limestone, fine, crystalline, light brownish gray, dolomitic and sandy, with many quartz grains rounded and frosted	10,074
3	Sandstone, fine- to medium-grained, light gray, quartzose, dolomitic; many quartz grains rounded and frosted	10,077
7	Sandstone, fine-grained, light brownish gray, quartzose, very dolomitic; many quartz grains rounded and frosted	10,084
4	Sandstone, fine-grained, light gray, quartzose, slightly dolomitic; many quartz grains rounded and frosted	10,088
8	Sandstone, fine- to medium-grained, white; mostly angular quartz grains with some rounded and frosted. One bailer salt water per hour at 10,092 feet	10,096
	Total depth	10,096

STRATIGRAPHIC SECTIONS

Four series of stratigraphic sections, based on well-sample records and drillers' logs, have been assembled for the northern Appalachian basin, as follows.

Section *AA'* (Fig. 3) starts with Well 1 (Fig. 1), in the northwestern part of Ohio and extends south of lakes Erie and Ontario to Well 14 in south-central New York.

Section *BB'* (Fig. 4) starts with Well 15, west of Lake Ontario and extends south approximately along the 79th meridian to Butler County, Pennsylvania.

Section *CC'* (Fig. 5) starts with Well 5 in north-central Ohio and extends southeast and south approximately along the 82d meridian to the Ohio River.

Section *DD'* (Fig. 5) starts with Well 25 in central Ohio and extends east to Well 23, about halfway to the Pennsylvania line. The four sections are drawn on the top of the Trenton limestone as previously defined. This horizon does not coincide everywhere with the top of the Trenton group, as shown in Figure 2.

SOURCE OF INFORMATION FOR STRATIGRAPHIC SECTIONS

SECTION AA'

No. 1.—Ohio Oil Company's Louis Barlage No. 1, Liberty Township, Putnam County, Ohio. Based on examination of drill cuttings by Chas. R. Fettke. Correlations in conformity with those of Cohee.[14]

No. 2.—J. E. Fennerty *et al.* D. L. Norris No. 1, Marion T., Hancock Co., Ohio. Based on examination of drill cuttings by D. D. Condit.[15] Correlations by Fettke. Condit placed strata between 729 and 1135 feet below top of Trenton in Lower Ordovician.

No. 3.—Ohio Oil Company's Bruns No. 1, Sandusky Co., Ohio. Based on examination of drill cuttings by Norval Ballard.[16] Correlations by Fettke. Ballard assigned interval between 633 and 991 feet below top of Trenton to Lower Ordovician.

No. 4.—C. W. White's Peter and Blanch Arting No. 1, Peru T., Huron Co., Ohio. Based on drillers' log. According to George D. Lindberg, oral communication, May 16, 1947, this well reached pre-Cambrian granite.

No. 5.—Ohio Oil Company's S. V. Krause No. 1, Ruggles T., Ashland Co., Ohio. Based on examination of drill cuttings by Chas. R. Fettke.

No. 6.—Hanley and Bird's Grant W. Pitts No. 1, Pittsfield T., Lorain Co., Ohio. Based on examination of drill cuttings by Chas. R. Fettke.

No. 7.—McCrea Oil and Gas Company *et al.* Billman No. 2, Spencer T., Medina Co., Ohio. Based on drillers' log.

No. 8.—East Ohio Gas Company's George W. Crile No. 1, Chardon T., Geauga Co., Ohio. Based on examination of drill cuttings by Chas. R. Fettke.

No. 9.—Ohio Fuel Gas Company's George E. Chester No. 1, Rome T., Ashtabula Co., Ohio. Based on examination of drill cuttings by Chas. R. Fettke.

No. 10.—Ohio Oil Company's Jay Childs No. 1, Springfield T., Erie Co., Pennsylvania. Based on examination of drill cuttings by Chas. R. Fettke.

No. 11.—Reservation Gas Company's George Button, Town of Collins, Erie Co., New York. Based on drillers' log. Reported to have been drilled 2 feet into granite.[17] Comparison with section obtained in Arcade well, 30 miles east, indicates dolomite probably mistaken for granite.

No. 12.—K. R. Wilson's Arcade No. 1, Town of Arcade, Wyoming Co., New York. Based on examination of drill cuttings by Chas. R. Fettke.

No. 13.—Reserve Oil Company's J. C. Mahaney No. 1, Town of Ledyard, Cayuga Co., New York. Based on examination of drill cuttings by Chas. R. Fettke.

No. 14.—Reserve Oil Company's Joe Farkas No. 1, Town of Lansing, Tomkins Co., New York. Based on examination of drill cuttings by Chas. R. Fettke.

SECTION BB'

No. 15.—Rockwood Oil and Gas Company's well, Lot 6, Con. IV, Eramosa T., Wellington Co., Ontario. Based on examination of drill cuttings by J. F. Caley.[18]

[14] George V. Cohee, "Sections and Maps of Lower Ordovician and Cambrian Rocks in the Michigan Basin, Michigan and Adjoining Areas," *U. S. Geol. Survey Prelim. Chart 9*, Oil and Gas Invest. Ser. (1945).

[15] D. D. Condit, "Deep Wells at Findlay, Ohio," *Amer. Jour. Sci.*, 4th Ser., Vol. 36 (1913), pp. 123–30.

[16] Norval Ballard, "Stratigraphy and Structural History of East-Central United States," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 22, No. 11 (1938), pp. 1152–54.

[17] D. H. Newland and C. A. Hartnagel, "Review of the Natural Gas and Petroleum Developments in New York State," *New York State Mus. Bull. 295*, p. 122.

[18] J. F. Caley, "Paleozoic Geology of the Brantford Area, Ontario," *Canada Geol. Survey Mem. 226* (1941), pp. 90–91.

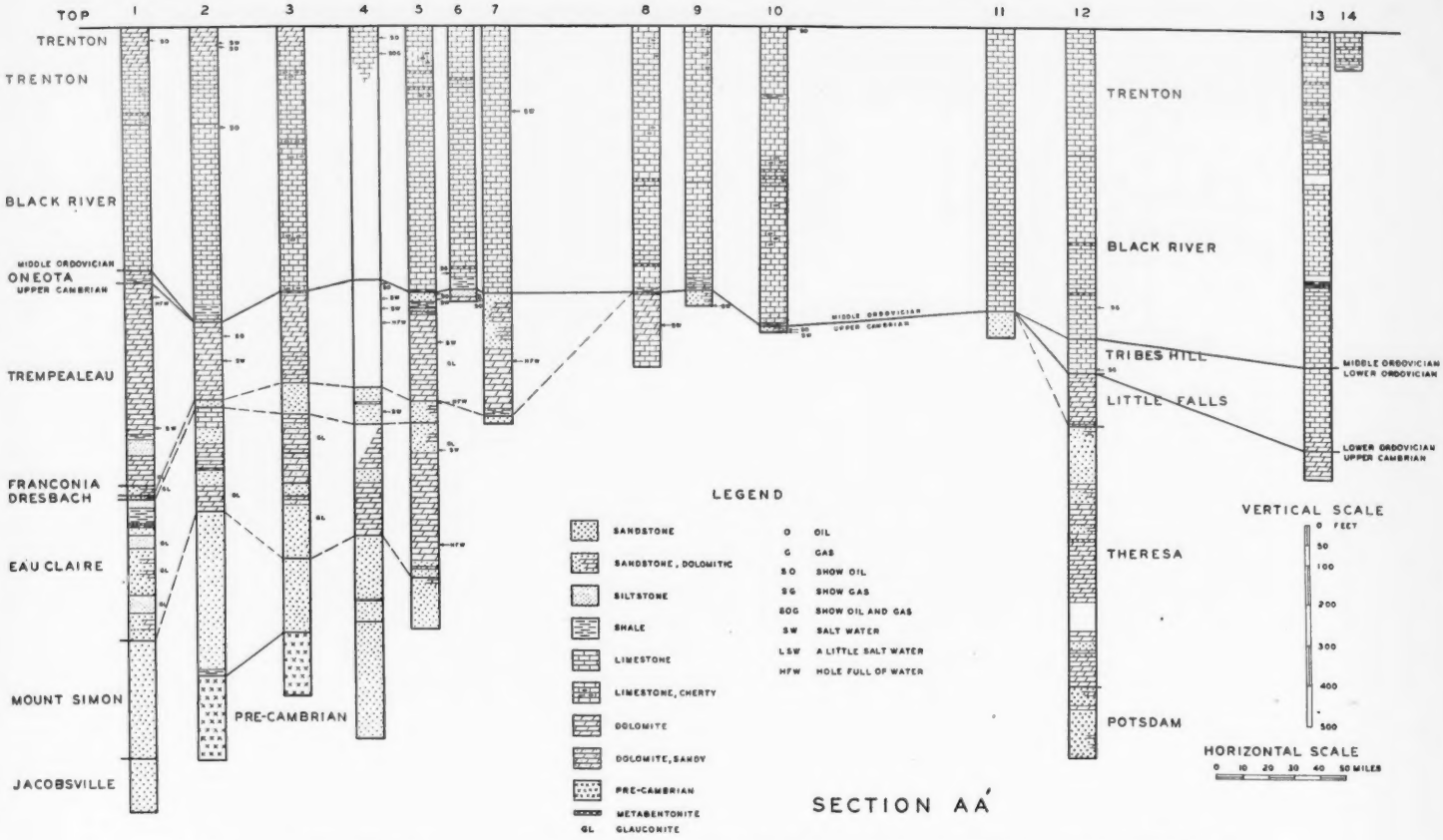


FIG. 3.—Stratigraphic section across northern part of Appalachian basin from northwestern Ohio to south-central New York.

FIG. 3.—Stratigraphic section across northern part of Appalachian basin from northwestern Ohio to south-central New York.

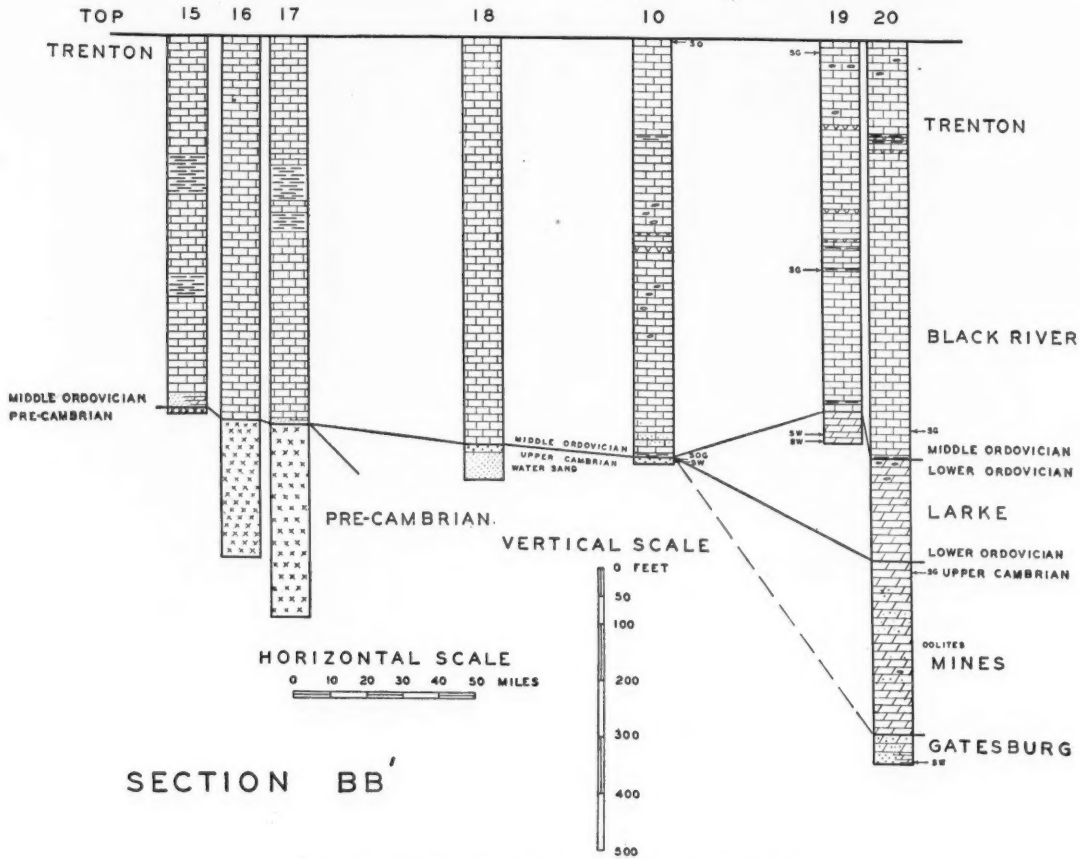


FIG. 4.—Stratigraphic section along 79th Meridian of Longitude.

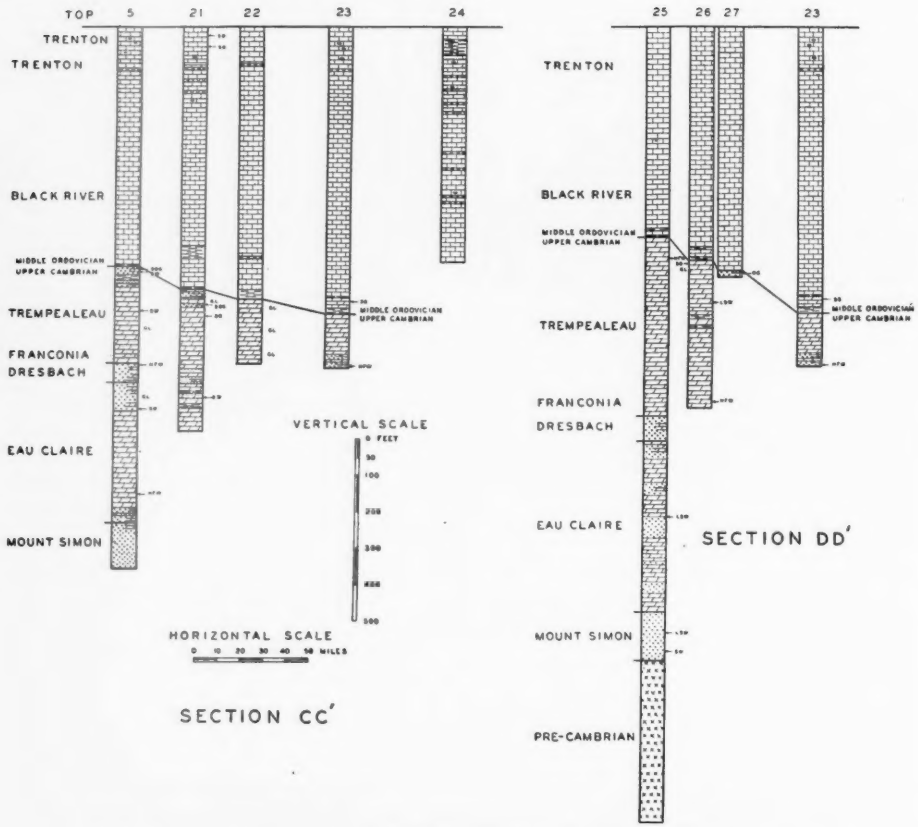


FIG. 5.—Stratigraphic sections along 82d Meridian of Longitude and across central Ohio.

No. 16.—Bollert Oil and Gas Comapny's well No. 1, Lot 7, Con. IV, Puslinch T., Wellington Co., Ontario. Based on examination of drill cuttings by J. F. Caley.[19]

No. 17.—Rockton Oil and Gas Company's well No. 3, Lot 30, Con. IV, Beverly T., Wentworth Co., Ontario. Based upon examination of drill cuttings by J. F. Caley.[20]

No. 18.—Dominion Natural Gas Company's Long Point, South Walsingham T., Norfolk Co., Ontario. Based on drillers' log. Harkness assigned bottom 50 feet, called water sand by drillers, to pre-Cambrian.[21] Recent exploration on opposite side of Lake Erie in northwestern Pennsylvania and western New York makes it appear doubtful that well reached pre-Cambrian.

No. 10.—Ohio Oil Company's Jay Childs No. 1.

[19] J. F. Caley, "Paleozoic Geology of the Toronto-Hamilton Area, Ontario," *ibid., Mem. 224* (1940), pp. 137–38.

[20] *Ibid.*, pp. 127–28.

[21] R. B. Harkness, "Gas and Oil in Eastern Ontario," *Ontario Bur. Mines, 46th Ann. Rept.*, Vol. 46, Pt. 5 (1937), cross section opp. p. 102.

No. 19.—United Natural Gas Company's Maude Davidson No. 1, Worth T., Mercer Co., Pennsylvania. Based on examination of drill cuttings by Chas. R. Fettke.

No. 20.—Manufacturers Light and Heat Company's Jessie G. Hockenberry No. 1, Mercer T., Butler Co., Pennsylvania. Based on examination of drill cuttings by Chas. R. Fettke. Total depth 10,096 feet; deepest well in Appalachian basin; deepest well drilled entirely with cable tools.

SECTION CC′

No. 5.—Ohio Oil Company's S. V. Krause No. 1.

No. 21.—Ohio Oil Company's J. H. Armstrong No. 8, Wooster T., Wayne Co., Ohio. Based on examination of drill cuttings by Chas. R. Fettke.

No. 22.—Ohio Oil Company's Chaney-Meyer, Unit 2, No. 1, Clark T., Coshocton Co., Ohio. Based on examination of drill cuttings by Chas. R. Fettke.

No. 23.—Industrial Gas Corporation's Sidney Whitmire No. 1, Salt Creek T., Muskingum Co., Ohio. Based on examination of drill cuttings by Chas. R. Fettke.

No. 24.—Sinclair Prairie Oil Company's George Longsworth No. 1, Olive T., Meigs Co., Ohio. Based on examination of drill cuttings by Chas. R. Fettke.

SECTION DD′

No. 25.—Chester L. Wise *et al.*, Herman E. Vance No. 1, Orange T., Delaware Co., Ohio. Based on examination of drill cuttings by Wilber Stout and Carl A. Lamey.[22] Correlations by Fettke. Stout and Lamey assigned the interval between 579 and 1030 feet below top of Trenton to Lower Ordovician.

No. 26.—S. D. and W. B. McCloy's Bertha Rowe No. 1, Jersey T., Licking Co., Ohio. Based on drillers' log.

No. 27.—W. W. and A. T. Wehrle No. 8, Newark T., Licking Co., Ohio. Based on drillers' log.

No. 23.—Industrial Gas Corporation's Sidney Whitmire No. 1.

CORRELATION

Wells in the northern part of the Appalachian basin that have reached the pre-Cambrian are confined to the margins of the basin. A number have been completed along the Cincinnati arch and its northwest fork, the Findlay arch. Of these, the Vance well, No. 25, in central Ohio is located on the western flank of the basin and farthest from the arch. Wells have also been drilled to the pre-Cambrian along the northern and northeastern rims of the basin in southern Ontario and on the southwest side of the Adirondack Mountains. Data on the total thickness and nature of the Lower Ordovician and the Cambrian rocks over most of the basin are lacking.

Along the northern margin of the basin in southern Ontario, Middle Ordovician limestones overlap the Cambrian and rest directly on the pre-Cambrian so that outcrop sections and marginal wells give no clue as to what may be present out in the basin. Along the southwest flank of the Adirondack Mountains, as pointed out by Ulrich and Cushing,[23] numerous gaps occur in the exposed sections of the Ordovician and Cambrian strata and the outcrop sections are relatively thin and imperfect. These conditions make it difficult to correlate the limited sections of pre-Middle Ordovician rocks that have been penetrated by wells in the basin.

[22] Wilber Stout and Carl A. Lamey, "Paleozoic and Pre-Cambrian Rocks of Vance Well, Delaware County, Ohio," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 4 (1940), pp. 672–92.

[23] E. O. Ulrich and H. P. Cushing, "Age and Relation of the Little Falls Dolomite (Calciferous) of the Mohawk Valley," *New York State Mus. Bull. 140* (1920), p. 137.

UPPER CAMBRIAN OR CROIXIAN SERIES

Cohee[24] has carried the subsurface correlation of the Trenton and sub-Trenton rocks from their outcrops around the western and southern margins of the Michigan basin to the Barlage well in northwestern Ohio (No. 1 on map, Fig. 1). The writer has accepted Cohee's interpretation of the section exhibited by the Barlage well and has extended the correlation across the northern part of the Appalachian basin to join to the extent that present exploration permits, the outcrops on the southwest flank of the Adirondack Mountains and in central Pennsylvania.

Altogether, 1314 feet of strata are assigned to the Upper Cambrian in the Barlage well. The lower 135 feet consist of grayish red, somewhat argillaceous sandstone with grayish red arkose at the base. This interval is correlated questionably with the Jacobsville sandstone of the northern peninsula of Michigan.[25] Cohee interprets the basal arkose as representing weathered pre-Cambrian granite. The Jacobsville sandstone is reported to be Upper Cambrian in age but this has not been established definitely. A similar sandstone was recognized by Wasson[26] in the Friend well, No. 29, Clark County, Ohio, in the interval from 3330 to 3419 feet. It was not encountered in the Vance well,[27] No. 25, in central Ohio.

Of the remaining 1179 feet of Upper Cambrian beds in the Barlage well, 292 feet are assigned to the Mt. Simon sandstone; 350 feet to the Eau Claire sandstone; 10 feet to the Dresbach sandstone; 25 feet to the Franconia sandstone; and 502 to the Trempealeau formation, in ascending order.

The Mt. Simon sandstone in the Barlage well consists of fine- to coarse-grained, light gray, quartzose sandstone, becoming light reddish gray toward the base. The Krause well, No. 5, had penetrated 126 feet of similar sandstone at the time that drilling was stopped. The 176 feet of sandstone assigned to the Potsdam at the bottom of the Arcade well, No. 12, are believed to occupy approximately the stratigraphic position of the Mt. Simon in the western wells.

The Eau Claire in the Barlage well consists predominantly of very fine- to medium-grained, somewhat dolomitic sandstone, but considerable dolomitic siltstone and a little shale are also present. Glauconite occurs in both the sandstone and the siltstone. In the Krause well, the Eau Claire is considerably more dolomitic and glauconite is only here and there present. In the Arcade well, the dolomitic part of the interval assigned to the Theresa, below the upper sandstone, probably corresponds in age with the Eau Claire.

[24] George V. Cohee, "Sections and Maps of Lower Ordovician and Cambrian Rocks in the Michigan Basin, Michigan and Adjoining Areas," *U. S. Geol. Survey Prelim. Chart 9*, Oil and Gas Invest. Ser. (1945).

[25] George V. Cohee, *op. cit.*

[26] Isabel B. Wasson, "Sub-Trenton Formations in Ohio," *Jour. Geology*, Vol. 40, No. 8 (1932), p. 686.

[27] Wilber Stout and Carl A. Lamey, "Paleozoic and Pre-Cambrian Rocks of Vance Well, Delaware County, Ohio," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 4 (1940), p. 687.

Ten feet of fine- to medium-grained brownish gray, somewhat dolomitic sandstone free from glauconite probably represent the Dresbach sandstone in the Barlage well. Both the overlying sandstone and the underlying siltstone contain glauconite. By definition, the Dresbach (Galesville) is free from glauconite or fossils.[28] In the Krause well, the Dresbach is represented by 57 feet of sandstone. The 141 feet of sandstone comprising the upper part of the interval assigned to the Theresa in the Arcade well and the lower 22 feet of sandstone of the 48 feet of strata allocated to the Gatesburg formation at the bottom of of the Hockenberry well, No. 20, occur approximately at the horizon of the Dresbach sandstone. The bottom 12 feet of sandstone in the Childs well, No. 10, originally correlated with the St. Peter,[29] are now thought to represent the Dresbach.

The Franconia sandstone as recognized in the Barlage well consists of 25 feet of fine- to medium-grained brownish gray dolomitic sandstone containing a little glauconite. This sandstone was not recognized as a distinct unit in any of the wells in central Ohio from which drill-cutting samples were examined.

The Trempealeau formation in the Barlage well consists largely of very fine, crystalline, relatively pure dolomite with minor amounts of interbedded dolomitic siltstone and shale. The dolomite becomes sandy and contains a little glauconite in its lower part. The Trempealeau contains more silt and sand in the Krause and other wells in central Ohio. No chert was observed in it in Ohio. In the Arcade and Mahaney wells, the interval assigned to the Little Falls dolomite is believed to be correlative with the Trempealeau and in the Hockenberry well the interval assigned to the Mines dolomite occupies approximately the same position.

The Trempealeau formation on the outcrop in Wisconsin,[30] in ascending order, consists of basal greensand and conglomerate, succeeded by dolomite, dolomitic siltstone, and fine-grained thin-bedded sandstones grading upward into massively bedded and coarser-grained sandstones. Fossils occur throughout the formation. The total thickness ranges from 60 to 175 feet in different sections. Cohee[31] has traced the Trempealeau in the subsurface around the western and southern margins of the Michigan basin and finds that it thickens to 700 feet in northern Indiana and to more than 500 feet in southeastern Michigan. It becomes predominantly a dolomite but retains its somewhat sandy nature in parts. Minor amounts of interbedded shaly dolomite and dolomitic shale occur in it.

[28] W. H. Twenhofel, G. O. Raasch, and F. T. Thwaites, "Cambrian Strata of Wisconsin," *Bull. Geol. Soc. America*, Vol. 46 (1935), p. 1697.

[29] Chas. R. Fettke, "Subsurface Sections Across Western Pennsylvania," *Pennsylvania Topog. and Geol. Survey Prog. Rept. 127* (1941), p. 6.

[30] W. H. Twenhofel, G. O. Raasch, and F. T. Thwaites, "Cambrian Strata of Wisconsin," *Bull. Geol. Soc. America*, Vol. 46 (1935), pp. 1705–12.

[31] George V. Cohee, "Sections and Maps of Lower Ordovician and Cambrian Rocks in the Michigan Basin, Michigan and Adjoining Areas," *U. S. Geol. Survey Prelim. Chart 9*, Oil and Gas Inves. Ser.

The 176 feet of very fine- to fine-grained, light gray to light brownish gray sandstone at the bottom of the Arcade well are thought to represent the Potsdam sandstone of the Adirondack region. The sandstone in the Arcade well possesses a finer texture than typical Potsdam sandstone but this may be accounted for by the fact that it was deposited farther from the source of the sand. Much of it is dolomitic. Considerable salt water was encountered about 70 feet below its top. The stratigraphic position of this sandstone corresponds with that of the Warrior limestone in central Pennsylvania.

The succession of interbedded, very fine, crystalline, brownish gray, sandy and silty dolomites and fine- to medium-grained light brownish gray sandstones that overlie the basal sandstone in the Arcade well are correlated with the Theresa formation of the northwestern Adirondacks, but the thickness is considerably greater, 643 feet as compared with a maximum of about 120 feet on the outcrop. The lithologic character of these beds is similar to that of the Gatesburg formation of central Pennsylvania. The 141 feet of sandstone, constituting the upper part, are believed to have the same stratigraphic position as the Dresbach sandstone in the western sections. A little salt water was encountered in the middle of this sandstone in the Arcade well. The bottom 48 feet of dolomitic sandy limestone and fine- to medium-grained light gray quartzose sandstone in the Hockenberry well are correlated with the Gatesburg formation of central Pennsylvania. The sandstone in which drilling was stopped when salt water was encountered appears to correspond in stratigraphic position with the Dresbach sandstone of the wells at the west.

The 130 feet of strata in the Arcade well and 68 feet in the Mahaney well, No. 13, that consist predominantly of fine, crystalline, light gray to light brownish gray dolomite, somewhat sandy and silty in part, have been correlated with the Little Falls dolomite of the New York section. No chert was observed in this dolomite. The lithologic character is very similar to that of the Trempealeau. In the Hockenberry well, 308 feet of only slightly sandy, fine, crystalline, brownish gray dolomite are correlated with the Mines dolomite of central Pennsylvania. A little chert is present in some of the beds comprising the interval and about 135 feet from the top, 15 feet of the dolomite contain considerable quantities of light gray siliceous oölites. The Mines dolomite on the outcrop in central Pennsylvania contains abundant chert. Siliceous oölites are common in it, but these are usually black in color instead of light gray. The Hockenberry is the only well in which any chert was observed in strata in the well sections that are correlated with the Trempealeau.

LOWER ORDOVICIAN OR CANADIAN SERIES

Thirty-three feet of very fine, crystalline, light brownish gray dolomite and light greenish gray dolomitic shale and siltstone have been questionably assigned to the Oneota in the Barlage well. Lower Ordovician strata were not recognized

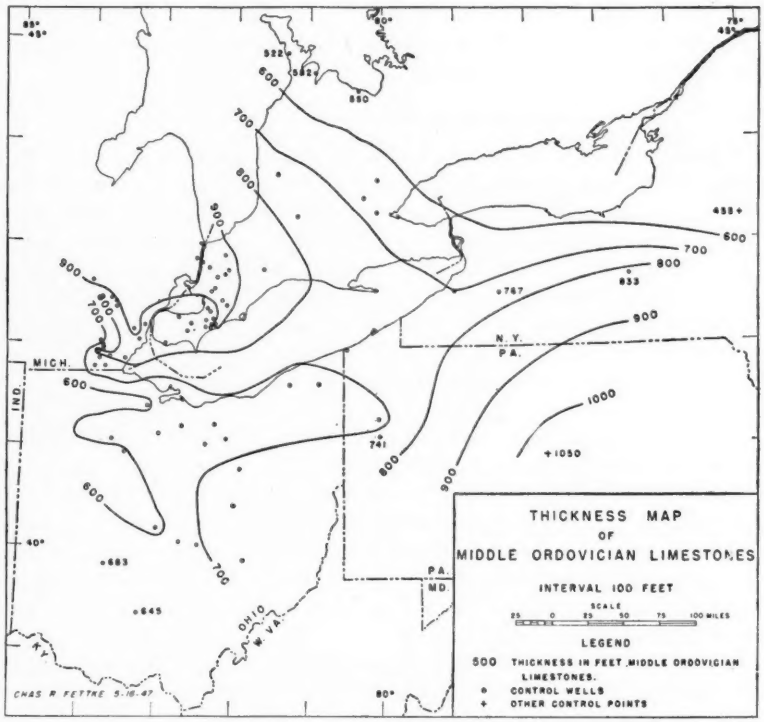


FIG. 6.—Thickness map of Middle Ordovician limestones in northern part of Appalachian basin.

in any of the wells in central Ohio. In south-central Ohio in the Walter Pierre well, No. 28, the lower 60 feet of section consists of very fine, crystalline, light gray, sandy dolomite containing a little light gray chert that may belong to the Oneota.

In the Hockenberry well in western Pennsylvania, 187 feet of relatively pure, fine, crystalline, light brownish gray dolomite containing almost no quartz grains and only a little light gray chert are correlated with the Larke dolomite of central Pennsylvania. Here and there, minute vugs, lined with tiny dolomite crystals, are present in this dolomite. Similar, but larger vugs, were observed in the outcrop of the Larke dolomite east of Williamsburg in central Pennsylvania.

The Tribes Hill limestone of the New York section and its equivalent, the Stonehenge limestone of central Pennsylvania, are believed to be represented by 86 feet of limestone in the Arcade well and 211 feet in the Mahaney well. The

limestones comprising this interval are fine in texture and argillaceous and magnesian in composition. They contain a few rounded and subrounded, frosted quartz grains. Some beds contain calcareous oölites.

MIDDLE ORDOVICIAN OR CHAMPLAINIAN SERIES

Middle Ordovician or Champlainian limestones underlie the entire Appalachian basin. Their thickness is shown on the map (Fig. 6). In the northern part of the basin, strata of Chazy age are probably confined to the eastern margin. In central Pennsylvania the Chazy is represented by 200 or more feet of strata which Kay has subdivided into the Loysburg and Hatter formations, in ascending order,[32] Butts included these in his Carlim limestone.[33] Strata of Chazy age are absent on the outcrop on the southwest side of the Adirondack Mountains and north of Lake Ontario.[34] None was recognized in the well sections in central and western New York, western Pennsylvania, and central and north-central Ohio.

Mohawkian limestones, comprising the Black River and Trenton groups of the Middle Ordovician, are present over the entire Appalachian basin. Stratigraphers and paleontologists are not yet in complete agreement about the correlation of the various formations and members that these two groups have been divided into on the outcrop around the margins of the basin. No attempt, therefore, has been made to separate the two groups in the well sections. Drillers commonly log this entire series of limestones under the term Trenton in the northern Appalachian area.

The Mohawkian limestones range in composition from argillaceous to almost pure limestone and in texture, from very fine, crystalline, to lithographic. In general, the upper part of the series is more argillaceous than the middle and lower parts and also more fossiliferous. Dolomites and dolomitic limestones are practically absent. Minor amounts of chert are present at certain horizons. Although shaly limestones are fairly common, true shales make up only a very small part of the section. In central and north-central Ohio, 5 or more feet of grayish green, calcareous shales, in part silty, commonly occur at what is believed to be the base of the Black River group. Thin beds of limestone, in places dolomitic, are in places interstratified with the shale and commonly contain some rounded and frosted quartz grains.

Bentonites occur as thin layers in the Black River and Trenton. The writer has observed them in most of the well sections in the northern part of the Appa-

[32] G. Marshall Kay, "Middle Ordovician of Central Pennsylvania," *Jour. Geology*, Vol. 52 (1944), pp. 3–15.

[33] Charles Butts, Geologic Section of Blair and Huntingdon Counties, Central Pennsylvania," *Amer. Jour. Sci.*, 4th Ser., Vol. 46 (1918), p. 526.

[34] H. P. Cushing, "Nomenclature of the Lower Paleozoic Rocks of New York," *Amer. Jour. Sci.*, Ser. 4, Vol. 31 (1911), p. 138.
G. Marshall Kay, "Ottawa-Bonnechere Graben and Lake Ontario Homocline," *Bull. Geol. Soc. America*, Vol. 53 (1942), p. 591.

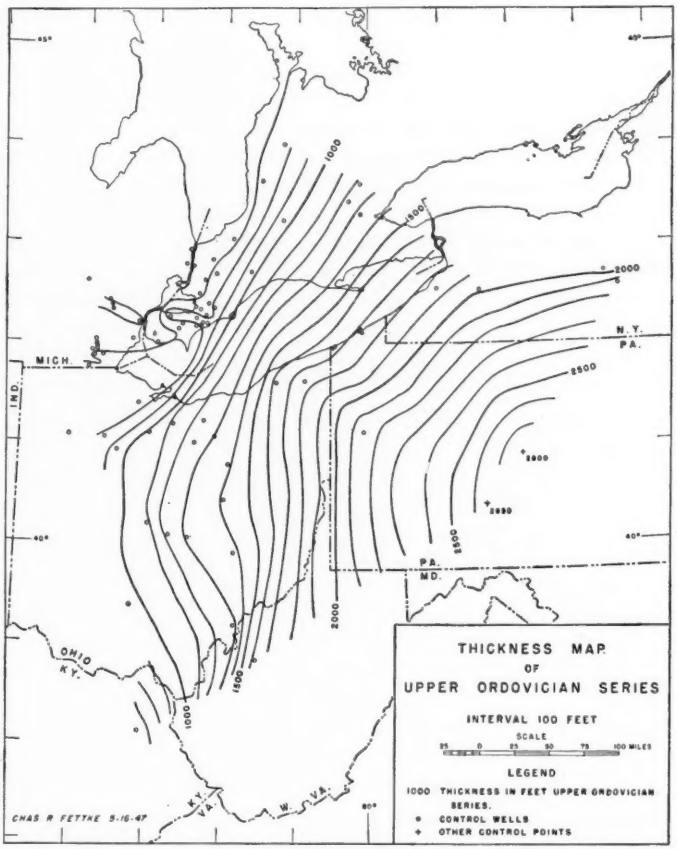


FIG. 7.—Thickness map of Upper Ordovician series in northern part of Appalachian basin.

lachian basin from which samples were available and others have described them from many localities on the outcrop.[35] In central Pennsylvania the lowest bentonite bed recognized thus far occurs in the upper part of the Stover limestone of

[35] C. A. Bonine and A. P. Honess, "Bentonites in Pennsylvania," *Pennsylvania Acad. Sci.*, Vol. 3 (1929), pp. 18–25.
Victor T. Allen, "Ordovician Altered Volcanic Material in Iowa, Wisconsin, and Missouri," *Jour. Geology*, Vol. 40 (1932), pp. 259–69.
Laurence Whitcomb, "Correlation by Ordovician Bentonite," *ibid.*, Vol. 42 (1932), pp. 522–34.
G. Marshall Kay, "Distribution of Ordovician Altered Volcanic Materials and Related Clays," *Bull. Geol. Soc. America*, Vol. 46 (1935), pp. 225–44.
Laurence Whitcomb and R. R. Rosenkrans, "Bentonite Beds in the Lower Chambersburg," *ibid.*, pp. 1251–54.
Arthur C. McFarlan, "Geology of Kentucky," *Univ. Kentucky* (1943), pp. 12–13.

the Black River group. Five beds are distributed through the Valley View limestone of the Black River. Two occur in the upper part of the Oak Hall limestone and seven or more in the Salona limestone of the Trenton group. In Tennessee, Fox and Grant have also found a bentonite bed in the Chazy and one in the lower part of Sequatchie formation of the late Upper Ordovician.[36] As more well-sample sections became available in the Appalachian basin, the bentonites undoubtedly will be valuable horizon-markers, not only for local but also for regional correlation. For example, the two bentonites in the upper part of the Oak Hall member of the Nealmont limestone in central Pennsylvania are probably the equivalent of the "Pencil Cave" and the "Mud Cave" bentonites which occur in the upper part of the Tyrone limestone in central Kentucky.[37]

UNCONFORMITY AT BASE OF MIDDLE ORDOVICIAN

In the northern part of the Appalachian basin, the most prominent unconformity in the Lower Paleozoic section occurs at the base of the Middle Ordovician. In the Arcade and Mahaney wells in south-central New York, the Black River limestone of the Middle Ordovician rests on the Tribes Hill limestone, the basal formation of the Lower Ordovician. All of the Chazy and most of the Beekmantown are missing. The exposed section on the southwest flank of the Adirondack Mountains, as has been pointed out, is very incomplete. Black River limestones, locally, rest on the Little Falls, the Theresa formation, the Potsdam sandstone, or the pre-Cambrian.

North of Lake Ontario the Black River rests on the pre-Cambrian.

In western Pennsylvania in the Hockenberry well the Black River limestone overlies what is probably a basal Lower Ordovician dolomite. All of the Chazy and most of the Beekmantown are missing, as in the Arcade and Mahaney wells. In central Pennsylvania in the vicinity of Bellefonte, 120 miles east of the Hockenberry well, this interval is represented by approximately 4500 feet of strata. There is no sharp lithologic break between the Chazy limestone of the Middle Ordovician which underlies the Black River limestone in central Pennsylvania and the Bellefonte dolomite of the Lower Ordovician. Possibly, as Kay has suggested,[38] the sandstone present in the upper part of the Bellefonte dolomite, south of Bellefonte, may occur at this boundary. The horizon of this sandstone is about 500 feet below the top of the Bellefonte dolomite at Bellefonte, but is scarcely recognizable there. The member has its best development about 5

[36] P. P. Fox and L. F. Grant, "Ordovician Bentonites in Tennessee and Adjacent States," *Jour. Geol.*, Vol. 52 (1944), pp. 319–32.

[37] G. Marshall Kay, oral communication, May 31, 1946.

[38] G. Marshall Kay, "Middle Ordovician of Central Pennsylvania," *Jour. Geol.*, Vol. 52 (1944), pp. 5–6.

miles south in the vicinity of Dale Summit where it has a thickness of 15 feet and forms a distinct ridge.[39]

It is believed that the sandstone encountered at 10,074 feet in the Hockenberry well, No. 20, is the equivalent of the one that occurs at 5179 feet in the Childs well, No. 10. The regional unconformity, apparently, cuts out 520 feet of strata in a distance of 65 miles in a slightly west-of-north direction in northwestern Pennsylvania. Similarly, if the two sandstones identified as Dresbach in the Vance No. 25, and the Krause No. 5, respectively, in central Ohio have been correctly correlated, the thickness of the combined Trempealeau and Franconia formations has been reduced by 225 feet in a distance of 65 miles in a northeast direction.

In central Ohio, as far south as the Vance No. 25, and the Whitmire No. 23, Black River limestone appears to rest on Trempealeau dolomites and dolomitic sandstones and siltstones. Beekmantown and Chazy strata apparently are absent. Early Beekmantown dolomites are encountered in wells on the west, south, and east. North and northeast, in southwestern Ontario and northeastern Ohio, the Black River limestone successively overlaps the beveled edges of older and older Upper Cambrian formations until finally it comes to rest on the pre-Cambrian.[40]

The Appalachian basin was submerged during most of Upper Cambrian time. The clastic parts of the Upper Cambrian sediments in the northern part of the basin were derived from low-lands on the north. During early Ordovician time a very broad and low southward-plunging arch developed, which extended into central Ohio from southwestern Ontario in the form of a low peninsula a little east of the present Findlay arch. Beekmantown dolomites continued to accumulate in adjacent seas while over the arch the Upper Cambrian strata were exposed to weathering and underwent a moderate amount of erosion. Later, Black River limestones were deposited unconformably over the older strata.

STRUCTURE

The Appalachian basin is a broad asymmetrical and complex structural trough or synclinorium whose long axis trends northeast and southwest, with the steep limb on the southeast side. On the southeast (Figure 1) it is bounded by closely folded Appalachians, on the northeast by the Adirondack Mountains and the Frontenac arch, on the north by the pre-Cambrian highlands of central Ontario, on the northwest by the Findlay-Algonquin arch, and on the west by the Cincinnati arch. Many of the formations of the basin extend considerable distances beyond the limits of the present structural trough.

[39] Charles Butts and Elwood S. Moore, "Geology and Mineral Resources of the Bellefonte Quadrangle, Pennsylvania," *U. S. Geol. Survey Bull. 855* (1936), pp. 30–31.

[40] George V. Cohee, "Cambrian and Ordovician Rocks in Recent Wells in Southeastern Michigan," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 31 (1947), pp. 303–5.

The regional structure of the northern part of the basin is shown in Figure 1 by means of contours drawn on the top of the Trenton limestone. Only the northwestern flank is included. The data for southeastern Michigan and adjacent parts of southwestern Ontario were taken from a map published by Cohee[41] and for the northern part of western New York, from one by Hartnagel.[42] The rest of the map is based on drillers' logs and well-sample records. In areas where wells have not reached the Trenton, the contours are shown as broken lines. In these areas the intervals from the deepest horizons penetrated by wells and the top of the Trenton were estimated by assuming that the rate of change in thicknesses of the formations involved is uniform between the nearest Trenton wells and the outcrop sections.

It will be noted in Figure 1 that the deepest part of the basin on top of the Trenton limestone is located very close to the Appalachian structural front. In Clearfield County, central Pennsylvania, it is estimated that the top of the Trenton limestone is approximately 11,000 feet below sea-level, whereas, less than 25 miles southeast the limestone crops out at elevations of 1100–1500 feet above sea-level. With respect to the surface beds, on the other hand, the central part of the basin is located in southeast Ohio, southeast Pennsylvania, and northwest West Virginia, where it is floored with beds of Permian age. The shift in the axis with depth is due in considerable part to the southeastward thickening of the great series of clastic deposits constituting the Upper Ordovician, Silurian, and Upper Devonian, respectively, particularly the last.[43] The thickness of the Upper Ordovician series is shown in Figure 7.

The regional structure of the basin is modified by a series of minor folds with axes trending approximately parallel with the long axis of the basin. On the southeast side these consist of strong, well defined anticlines and synclines, but northwestward the intensity of folding diminishes so that the folds become less prominent in the central part of the basin and disappear in the northwest part. The Chestnut Ridge anticline (Fig. 1) is the westernmost of the more prominent folds. Deep drilling for Oriskany gas has revealed that these folds are much more complex structurally than had been anticipated from the earlier surface mapping. It has been found that extensive, commonly northwest-dipping, reverse faults intersect and complexly modify the outlines of the more prominent domes along the anticlinal axes at the Oriskany horizon. Vertical separations of as much as 850 feet have been encountered at this horizon. Although some of the faults have been recognized on the outcrop, no displacements of this magnitude have been observed.

[41] George V. Cohee, *op. cit.*

[42] Chris A. Hartnagel, "The Medina and Trenton of Western New York," *ibid.*, Vol. 22 (1938), p. 90.

[43] Chas. R. Fettke, "Subsurface Studies in Connection with Deep Oil and Gas Sand Explorations in Pennsylvania," *Pennsylvania State College, School of Mineral Indus. Exp. Sta. Bull. 30* (1940), p. 41.

The synclinorium which constitutes the Appalachian basin of today came into existence during the Appalachian revolution at the close of the Paleozoic era. It was at this time that its southeastern rim was established. However, many of the prominent structural features of the basin antedate that revolution and later earth movements have produced some modifications.

OIL AND GAS POSSIBILITIES

The Trenton and sub-Trenton rocks have yielded a little oil and a small amount of gas in the Appalachian basin. Although the quantities have been almost negligible, the occurrences have demonstrated that the rocks do contain oil and gas in places. Inasmuch as only a small part of the area can be considered to be adequately tested, it seems probable that there are areas where conditions existed in these rocks that were favorable for the accumulation of larger deposits. The Trenton and sub-Trenton rocks of the Appalachian basin can be considered to offer definite possibilities as potential sources of gas and oil.

TRENTON

The Trenton has been an important source of both oil and gas along the Findlay arch which borders the Appalachian basin on the northwest. Cohee estimates that 479,000,000 barrels of oil have been obtained from 577,000 acres in the Lima-Indiana field.[44] The oil has been produced chiefly from the upper 50 feet of the Trenton and commonly from the upper 25 feet, but some has come from lower levels, 100–300 feet below the top of the limestone. The oil does not occur at any definite horizon.

Orton early recognized that the accumulation of oil in commercial quantities in the Trenton limestone in the Lima-Indiana field was confined to areas where the limestone had undergone local dolomitization.[45] Carman and Stout state that a magnesium carbonate content of at least 20 per cent is necessary for production and the best production is found where the rock is a true dolomite.[46] Landes has recently advanced the theory that local diastrophism produced master fissures in the limestone-containing section; that an artesian circulation developed which carried waters through deeper dolomites and up into the limestone; and that these waters replaced some of the limestone by dolomite that is locally porous where there was an excess of solution over precipitation during the replacement process.[47]

[44] George V. Cohee, "Geology and Oil and Gas Possibilities of Trenton and Black River Limestones of the Michigan Basin, Michigan and Adjacent Areas," *U. S. Geol. Survey Prelim. Chart 11*, Oil and Gas Inves. Ser. (1945).

[45] Edward Orton, "The Trenton Limestone as a Source of Oil and Gas in Ohio," *Geol. Survey Ohio*, Vol. VI (1888), pp. 307–8.

[46] J. Ernest Carman and Wilber Stout, "Relationship of Accumulation of Oil to Structure and Porosity in the Lima-Indiana Field," *Problems of Petroleum Geology*, Amer. Assoc. Petrol. Geol. (1934), p. 528.

[47] Kenneth K. Landes, "Porosity Through Dolomitization," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 30 (1946), pp. 305–18.

Six shallow gas pools have been opened in the Trenton on the southwest side of the Adirondack Mountains at the east end of Lake Ontario in New York (Fig. 1). The earliest discoveries were made 60 years ago. None of the pools has been large, but some have been long-lived. The output has been consumed locally. According to Hartnagel, the limestone beds are not dolomitic and they do not possess sufficient porosity to serve as reservoir rocks. The gas is found in cavities, seams and joints in shale partings and shale beds and in the limestone itself. Coral reefs within the Trenton are also believed to serve as a source of some of the gas. The gas does not occur at any definite horizon. In a single well, gas may be found at as many as 20 horizons distributed through the entire thickness of the formation.[48]

The recent discovery of oil in commercial quantities in the Trenton limestone on the Powell Valley anticline at Rose Hill in the southwest corner of Virginia is encouraging. It reveals that locally the early Paleozoic rocks still retain some oil, even east of the structural front where they have undergone considerable deformation. According to Miller and Fuller, the oil in the Trenton at Rose Hill does not occur in pore spaces inherent in the original rock or in open spaces that have been induced by dolomitization of the limestone. The oil is probably present in small fractures formed by the shattering of the rock during the period of folding and overthrusting. The oil is not confined to a single stratigraphic zone in the Trenton, and wells only a few hundred feet apart produce from widely separated zones. One well has produced oil from a limestone below the Trenton.[49]

Considerable exploratory drilling has been conducted in the Trenton limestone in northwestern New York and central Ohio where the limestone is relatively shallow. Results have been disappointing. No areas of local dolomitization in the Trenton limestone similar to the occurrence along the Findlay arch in northwestern Ohio and adjacent parts of Indiana have been discovered. Where the Trenton rocks outcrop in central Pennsylvania there is no evidence of local dolomitization along major anticlinal folds.

There is a possibility, however, that the Trenton limestone may have undergone sufficient fracturing along the crests of some of the stronger anticlines in the eastern part of the Appalachian basin to act as a reservoir rock for the accumulation of oil and gas. Unfortunately, as shown in Figure 1, the Trenton limestone is so deeply buried under these structures that it is questionable whether its exploration at present is economically feasible. There is one locality, however, in the vicinity of Schellsburg, Bedford County, in south-central Pennsylvania where the depth is not prohibitive. In this area, the belt between the

[48] Chris A. Hartnagel, "The Medina and Trenton of Western New York," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 22 (1938), pp. 88–99.

[49] Ralph L. Miller and J. Osborn Fuller, "Geologic and Structure Contour Maps of the Rose Hill Oil Field, Lee County, Virginia," *U. S. Geol. Survey Prelim. Map 76*, Oil and Gas Inves. Ser., Sheet 2 (1947).

topographic front and the structured front is wider. Erosion has uncovered the Oriskany sandstone of the Lower Devonian along the axis of a prominent elongate dome for a distance of about 5 miles.

SUB-TRENTON

It is not exceptional to encounter showings of oil and gas and frequently considerable salt water in dolomitic sandstones and sandy dolomites at or near the unconformity at the base of the Black River limestone. Heretofore, the strata immediately below the unconformity in central Ohio have been called St. Peter sandstone, as it was thought that they occurred at a definite horizon that could be correlated with the St. Peter sandstone of the Upper Mississippi Valley.

The writer has observed that the so-called St. Peter sandstone of Ohio varies considerably in lithologic character from place to place, ranging from dolomitic sandstone to almost pure, finely crystalline dolomite. The latter is frequently mistaken for sand by the drillers. It has also been found that the strata immediately below the unconformity are not of the same age in all wells, but become younger southward in central Ohio.

A small amount of oil has been obtained from sandy zones in what is believed to be the Trempealeau formation at four localities in Ohio, namely, at Tiffin (No. 30 on map, Figure 1), in Seneca County; at Caledonia, No. 31, in Marion County; at Pickerington, No. 32, in Fairfield County; and at Newark, No. 27, in Licking County. In the vicinity of Tiffin, three wells produced oil, the best one of which had an initial production of 500 barrels daily, but soon declined to about 25 barrels. At Caledonia, four producing wells were drilled in 1918, which had initial productions ranging from 15 to 745 barrels of oil per day. At Pickerington a well drilled in 1920 found 10 feet of "pay sand" which produced about 8 barrels of oil daily.[50] At Newark about eight wells were drilled in 1924 and 1925 with initial open flows ranging from 85,000 to 250,000 cubic feet of gas per day and some oil. One well averaged 65 barrels of oil per day for 11 days. In Pittsfield Township, No. 6, Lorain County, a well drilled in 1946 had a settled production of 66,000 cubic feet of gas per day from a silty dolomite bed, 20 feet below the unconformity.

Of 67 available records of wells that penetrated strata below the Black River in central Ohio, 27 reported showings of oil and gas, some accompanied by salt water, a short distance below the unconformity, less than 40 feet. Of those that were drilled appreciable distances below the unconformity, very few reported any additional showings of oil or gas. Salt water, on the other hand, has been encountered, commonly in considerable volumes, even as deep as the Mt. Simon sandstone.

As most oil and gas showings reported from the Upper Cambrian rocks in central Ohio occur close to the unconformity and as, in most instances, only

[50] L. S. Panyity, "Oil and Gas Bearing Horizons of the Ordovician System in Ohio," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 5 (1921), pp. 609–19.

salt water has been found at greater depths, it seems possible that there has been some updip migration of oil and gas along porous and permeable members which has been trapped beneath the unconformity. This suggests the possibility that there may be places where porous and permeable layers of sufficient thickness and areal extent occur in these rocks to have permitted the accumulation of pools of significant size where local structural conditions were favorable. The number of sub-Trenton wells in central and northeastern Ohio, northwestern Pennsylvania, and western New York is relatively small for the area involved.

Showings of gas have been encountered in the Little Falls dolomite in a well in Herkimer County and one in Madison County, New York, and in the Potsdam sandstone in a well in Oswego County. These occurrences are on the southwest side of the Adirondack Mountains.

The possibilities of the sub-Trenton rocks beneath the stronger anticlines in the eastern part of the Appalachian basin are intriguing. The great depth, however, probably precludes their early exploration. As has been pointed out, the hiatus at the unconformity beneath the Black River in the Hockenberry well, No. 20, is represented by approximately 4500 feet of strata, mostly dolomites and limestones, 120 miles east in the vicinity of Bellefonte. The disappearance westward of these strata is due partly to non-deposition and partly to truncation by the unconformity.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 8 (AUGUST, 1948), PP. 1493-1595, 26 FIGS., 3 TABLES

TRENTON AND SUB-TRENTON OF OUTCROP AREAS IN NEW YORK, PENNSYLVANIA, AND MARYLAND[1]

FRANK M. SWARTZ[2]
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ABSTRACT

Trenton and sub-Trenton rocks of the outcrop regions in New York, Pennsylvania, and Maryland are described, and their conditions of origin and paleogeography are discussed. The basement rocks are considered with respect to regional characters, possible causes of magnetic and isostatic anomalies, and relation to deformation of the Paleozoic sediments. New stratigraphic charts, and new isopachous and paleogeographic maps are presented for the Glenarm, the Lower Cambrian, the Middle and Upper Cambrian, the Lower Ordovician, and the Middle Ordovician sediments of the region, with accompanying discussions of the stratigraphy, regional relations, and sedimentation of the deposits. Brief consideration is given to relations of the Trenton and sub-Trenton at the outcrop in New York, Pennsylvania, and Maryland, with respect to search for oil and gas in the more westerly subsurface areas of these sediments.

INTRODUCTION

Trenton and sub-Trenton Paleozoic strata reach the surface in New York, Pennsylvania, and Maryland, along the following belts of outcrop (Fig. 1).

1. New York
   a. Flanks of Adirondack Mountains
   b. Hudson River Valley
2. Pennsylvania and Maryland
   a. Limestone valleys and quartzite hills southeast of Triassic Lowland, and possibly in Glenarm region
   b. South Mountains, Reading Prong, and Great Valley, north and northwest of Triassic Lowland
   c. Anticlinal valleys of Ridge and Valley Province

In New York, Trenton and sub-Trenton Paleozoic strata have been studied especially by H. P. Cushing, Rudolf Ruedemann, G. Van Ingen, P. E. Raymond, G. M. Kay, and W. J. Miller; in Pennsylvania and Maryland, extensive work has been done by G. W. Stose, A. I. Jonas, R. S. Bassler, Charles Butts, Ernst Cloos, G. M. Kay, and B. L. Miller. (See papers by these and other authors, listed in appended bibliography.) The present discussion represents an attempt to bring together and correlate in summary fashion data made available by these and other geologists and to give consideration to problems of stratigraphic relations, conditions of deposition, and factors affecting oil and gas accumulation and exploration. No new field investigations have been made; but new stratigraphic charts and new, preliminary ispachous maps have been prepared from the published accounts.

ORDER OF DISCUSSION

The discussion of the Trenton and sub-Trenton rocks of the outcrop regions in New York, Pennsylvania, and Maryland is arranged under the following major headings.

[1] Published by permission of the State Geologist of Pennsylvania and of the Dean, School of Mineral Industries, The Pennsylvania State College. Manuscript received, May 17, 1948.

[2] Chief, Division of Geology, The Pennsylvania State College.

Pre-Cambrian basement
Lower Cambrian
Middle and Upper Cambrian
Lower Ordovician
Middle Ordovician Chazyan deposits
Middle Ordovician Black River and Trenton deposits
Relations of Trenton and sub-Trenton at outcrop in New York, Pennsylvania, and Maryland, with respect to search for oil and gas in subsurface areas farther west

Each of these major topics is further subdivided. Areal geologic maps, stratigraphic charts, and preliminary isopachous maps accompany and illustrate the text material.

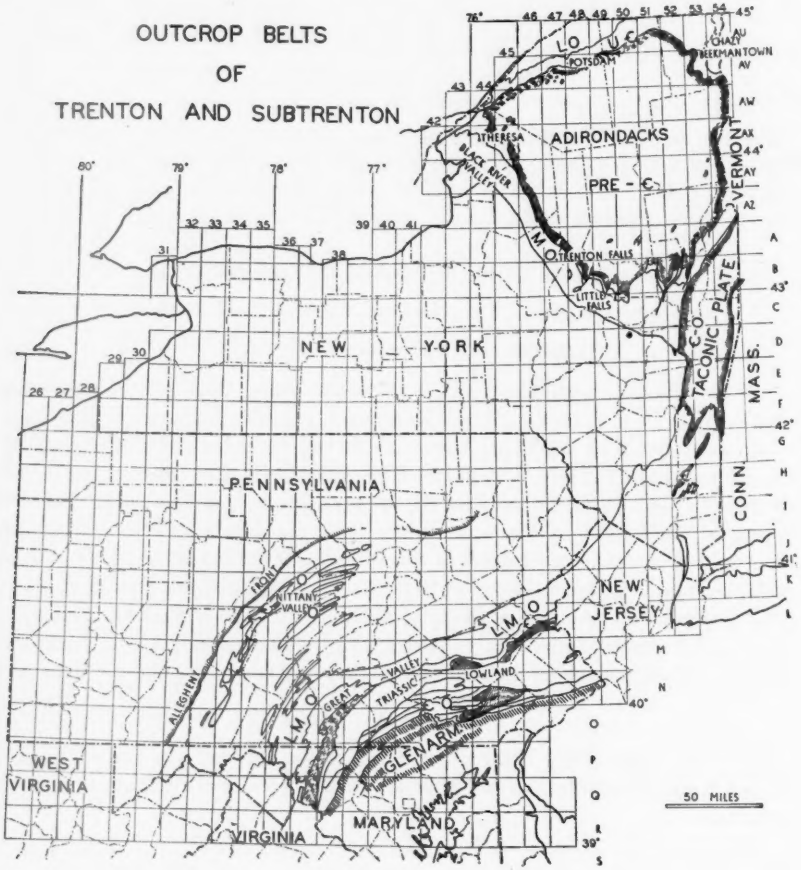

FIG. 1.—Index map illustrating areal geology of Trenton and sub-Trenton in New York, Pennsylvania, and Maryland.

Pre-Cambrian Basement

GENERAL CONSIDERATIONS

The pre-Cambrian basement of Pennsylvania, Maryland, and New York has no promise either for reservoir sites for oil and gas occurrence, or as the source for petroliferous materials of present-day oil and gas accumulations. Nevertheless, the basement and its rocks are of interest in considering the oil and gas relationships of the Trenton and sub-Trenton strata of the region because, first, they must have furnished materials of which some of the early Paleozoic deposits are composed; second, their surface relief doubtlessly affected to some degree the distribution and characters of the initial Paleozoic sediments laid upon them; third, the basement may have had structural trends significant in determining the geography of Paleozoic sedimentation; fourth, the basement rocks presumably took part in transmission of forces by which Trenton and sub-Trenton strata were deformed subsequent to their deposition; fifth, magnetic and gravimetric investigations attempting to deal with deep structures must take into account the inherent complexity of the pre-Cambrian rocks physically as well as chemically.

Too little is known of the pre-Cambrian of the region to afford full analysis of any one of the listed relationships. Nevertheless, it appears profitable to review known features of the pre-Cambrian in its regions of outcrop, in an attempt to secure helpful clues. Relief of surface of the pre-Cambrian complex, and other relations to Paleozoic deposits, will generally be considered in discussions of appropriate Cambro-Ordovician sediments.

AREAL DISTRIBUTION OF PRE-CAMBRIAN OUTCROPS

Rocks of accepted pre-Cambrian age are widely exposed in New York in the Adirondack Mountains, and are found in limited areas in the southern part of the Hudson River Valley. In Pennsylvania and Maryland, pre-Cambrian terranes are exposed: first, in the Reading Prong and Honeybrook Upland, north and south, respectively, of the Triassic Lowland in eastern Pennyslvania; second, in the South Mountains just west of the Triassic belt in south-central Pennsylvania and the adjacent part of Maryland. In a third region, southeast of the Martic Line, there are widespread Glenarm metamorphics whose possible pre-Cambrian age has given rise to vigorous controversy.

The pre-Cambrian masses of each of these areas are briefly considered.

PRE-CAMBRIAN OF ADIRONDACKS

The pre-Cambrian rocks of the Adirondacks include in order of increasing age the following main masses, according to Buddington (1939).

(Subordinate diabase dikes and some gabbros)

(5) Granite series
(4) Pyroxene quartz syenite and granite series
(3) Diorite series

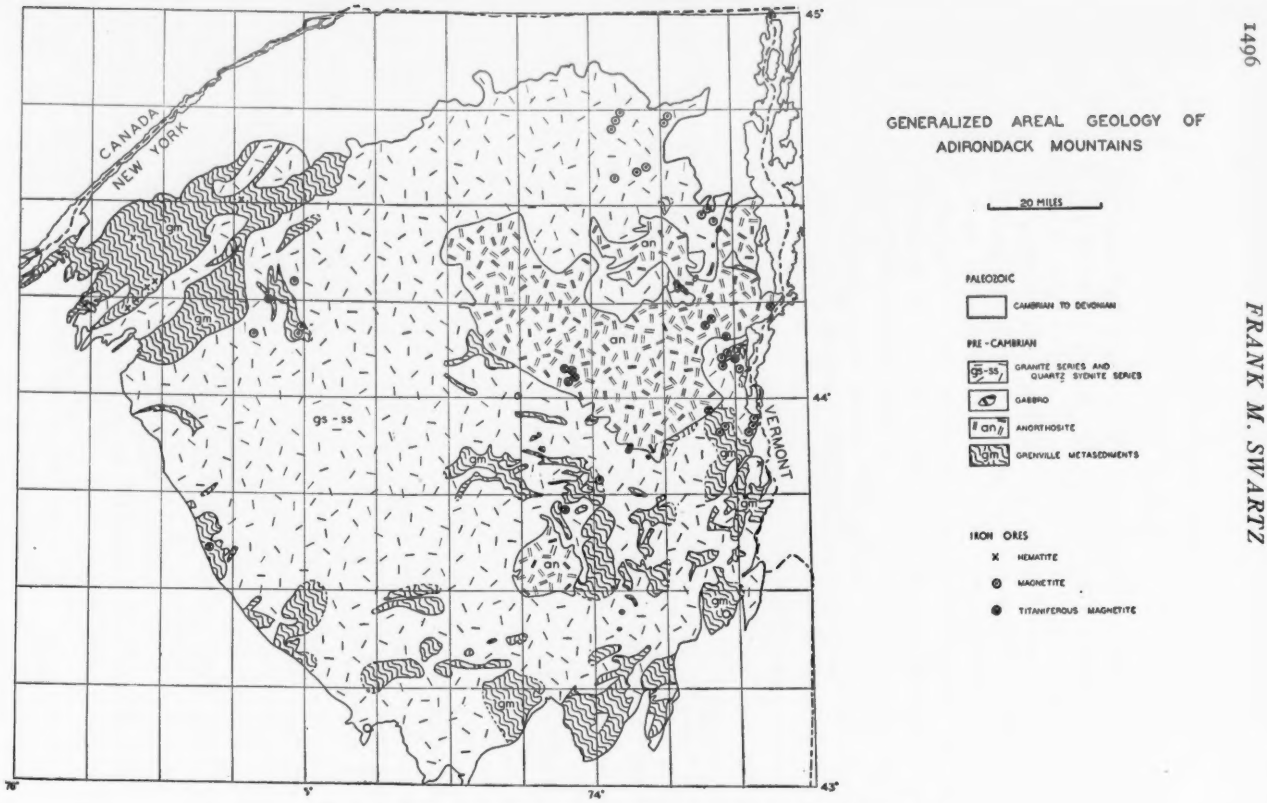

FIG. 2.—General areal geology of pre-Cambrian of Adirondack Mountains.

(2) Anorthosite series, with associated gabbro and metagabbro (Local granites; pre-anorthosite age not well established)
(1) Grenville series, consisting of coarse-textured marbles, quartzites, schists, amphibolites, migmatites

The larger features of the areal geology of the Adirondacks are illustrated in Figure 2. The granite and syenite series (4 and 5 of Buddington's list) are widely exposed. They occur in part as large stocks and batholithic masses, in part as smaller bodies intricately penetrating the Grenville metasediments. The diorite series (3) is subordinate, and local in its occurrence. The anorthosite (2) occurs in a major massif in the eastern Adirondacks, where it helps to produce some of the most rugged relief of the mountain area. A smaller body of the anorthosite occurs farther south. The marginal parts of the anorthosite tend to be somewhat gabbroic, and local, small bodies of gabbro are associated with the massif. The ancient Grenville sediments (1), originally believed to be continuous across the Adirondack region, have been intruded, sharded, and affected by the intrusive complexes so that their remnants are limited in extent, strongly metamorphosed, and pass at many places into migmatitic rocks containing large proportions of igneous materials.

Superimposed upon this larger pattern there is a wealth of smaller features. Buddington (1939) has illustrated many types of geologic complexities that have resulted from invasion of successive igneous intrusions into the ancient Grenville sediments and into each other. In part the syenite and granite intrusions occur along fold axes of the Grenville, in a fashion to complement axial thickening of the strata.

Before deposition of the Cambrian strata of the region, the pre-Cambrian rocks were deeply truncated by erosion. The Cambrian sediments were spread over a surface of low relief that had not only cut across the granite-intruded folds of the Grenville rocks, but had also uncovered presumably deep-seated intrusive masses of the granite, syenite, and anorthosite series.

Significant bodies of iron ore occur in the pre-Cambrian of the Adirondacks, and in general are associated with Grenville remnants. Locations of important concentrations of hematite, magnetite, and titaniferous ores are plotted in Figure 2 after Newland (1908).

The pre-Cambrian of the Adirondacks is complex in its geophysical as well as geologic characters. Local concentrations of magnetite ore produce strong magnetic effects, illustrated in Figure 3 by an isogammous map of the Benson mine area of the Oswegatchie Quadrangle, simplified from aero-magnetic *Preliminary Map 1, Geophysical Investigations, United States Geological Survey* (1946). Along the belt of Grenville metasediments and associated microcline granite gneiss in which the Benson Mines are located, magnetic values measured at 1,000 feet above surface vary from minus 700 to plus 3,500 gammas. There is little magnetic relief over near-by areas of hornblende granite gneiss; but approximately 10 miles west of Benson Mines a belt of quartz syenite furnishes a 1,500-gamma high, presumably again due to increased magnetite content.

FIG. 2.—General areal geology of pre-Cambrian of Adirondack Mountains.

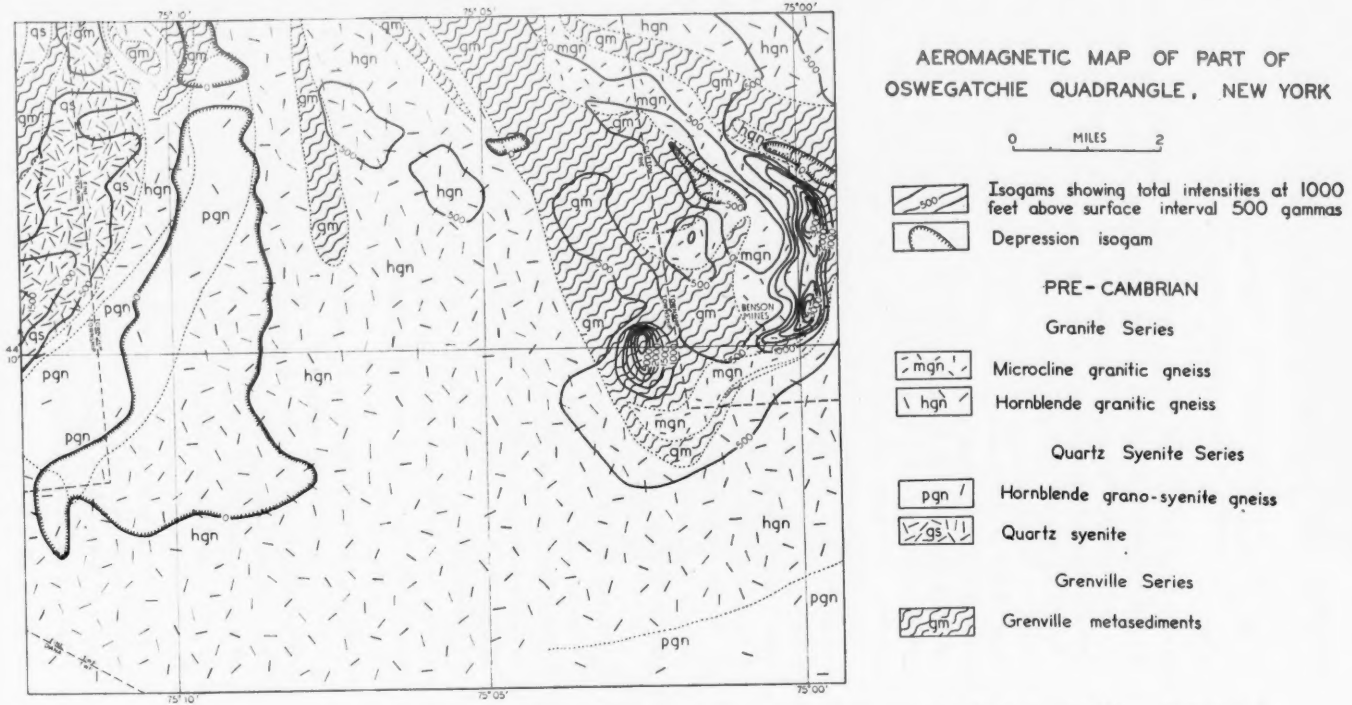

FIG. 3.—Areal geology and magnetic anomalies of Benson Mine area of Oswegatchie Quadrangle, New York. Simplified from *Preliminary Map 1, Geophysical Investigations, United States Geological Survey.*

The Benson Mine map suggests that where a pre-Cambrian complex such as that of the Adirondacks is buried beneath younger sediments, the magnetic variations due to changing magnetic susceptibilities of the constituent members may greatly outweigh variations due to relief of the buried surface of the complex. Large bodies of magnetite ore, such as occur at various localities in the pre-Cambrian of the Adirondacks (Fig. 2), would produce marked magnetic anomalies even where buried below several miles of sediments. More moderate percentages of magnetite, if disseminated through large rock masses, would likewise produce

TABLE I

RANGES IN PERCENTAGE OF MAGNETITE AND ILMENITE IN SAMPLES OF ADIRONDACK ROCKS
(Buddington, 1939)

Rock Type	*Number of Determinations*	*Percentage Magnetite (Norms)*	*Percentage Ilmenite (Norms)*
Grenville amphibolite	2	4.4–4.9	3.3–4.3
Pitcairn gneiss complex	2	1.4–6.3	0.8–1.1
Anorthosite of main massif	5	0.9–2.0	0.4–3.0
Gabbroic anorthosite, and norite and gabbro areas of anorthosite massif	11	0.8–4.9	Trace-13.1
Rocks from anorthosite-Grenville contact zones	10	Trace–5.1	Trace–6.9
Metagabbros of northwestern and eastern Adirondacks	19	1.6–7.2	0.6–9.7
Rossie diorite	5	0.9–8.7	Trace–6.0
Quartz syenites of Diana, Santa Clara, and other complexes	34	Trace–11.1	Trace–8.1
Hornblende granite	5	1.4–4.2	Trace–1.0
Herman and Antwerp granites	10	0.2–3.5	Trace–1.5

significant anomalies. To exemplify normal variations in magnetic qualities of several rock types, Tables I and II have been prepared, summarizing respectively Buddington's (1939) records of magnetite and ilmenite in rock samples from the Adirondacks, and Birch's (1942) data on the general variations of magnetic susceptibility in common rock types.

Significant gravimetric as well as magnetic variations can be expected in such rocks as those that compose the pre-Cambrian of the Adirondacks. Density determinations for Adirondack specimens have not been obtained. However, some guide to the order of magnitude of expectable differences in density, and thus of gravimetric variations, is furnished in Table III from data given in the *Handbook of Physical Constants* (Birch *et al.*, 1942).

PRE-CAMBRIAN OF READING PRONG AND HONEYBROOK UPLAND OF EASTERN PENNSYLVANIA

Pre-Cambrian rocks are exposed in eastern Pennsylvania in the Reading Prong of the Jersey Highlands, just north of the Triassic Lowland, and also in the Honeybrook Upland which adjoins the Triassic on the south (Figs. 4, 5).

The pre-Cambrian rocks of these eastern Pennsylvania areas consist of ancient, highly deformed gneisses of sedimentary origin, intruded by stock-like, plutonic masses of gabbro, anorthosite, and granitic rocks.

TABLE II

VARIATIONS IN MAGNETIC SUSCEPTIBILITY IN COMMON ROCK TYPES
(*Handbook of Physical Constants* (Birch *et al.*, 1942)

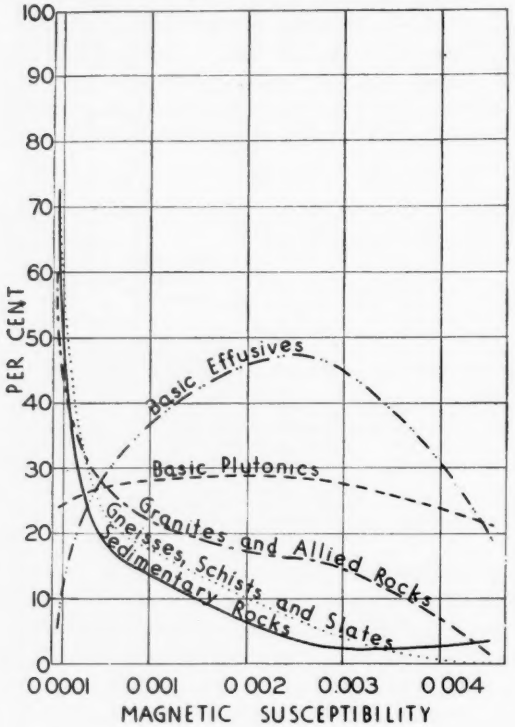

TABLE III

DENSITIES OF MINERALS AND ROCK TYPES
(*Handbook of Physical Constants* (Birch *et al.*, 1942)

Mineral Species or Rock Type	*Number of Samples*	*Average Density*	*Range in Density*
Magnetite			4.97–5.18
Quartz		2.654	
Quartzite	2	2.555	2.48–2.63
Calcite		2.717	
Marble	34	2.76	2.66 –2.86
Granite	155	2.667	2.516–2.809
Syenite	24	2.757	2.630–2.899
Diorite	13	2.839	2.731–2.960
Gabbro and diabase	67	2.970	2.803–3.120
Anorthosite	12	2.734	2.640–2.920
Pyroxenite and peridotite	11	3.233	3.10 –3.318

The pre-Cambrian complexes were deeply truncated by erosion prior to the time when Lower Cambrian sediments were spread upon them. Mapping of the Cambrian-pre-Cambrian boundary suggests that the erosion surface was well peneplaned.

The pre-Cambrian rocks and rock-history of the Reading and Honeybrook uplands are thus comparable with those of the pre-Cambrian of the Adirondacks in sedimentary-plutonic succession, in metamorphism and general structure, and in deep erosional truncation preceding deposition of the Cambrian. They furthermore are probably comparable with the pre-Cambrian rocks of the Adirondacks in their variations in magnetic and gravimetric properties.

Structurally, the rocks of the Reading Prong and Honeybrook Upland are of further interest because they provide the main exposures, in the Pennsylvania-New York area, of the Cambrian-pre-Cambrian boundary surface where affected by folding of the Paleozoics. Of special interest is the problem: did the Paleozoics, at the time of their deformation, shear across the pre-Cambrian basement so that their folds are in general discordant with the pre-Cambrian surface? Or did the pre-Cambrian mass yield in reasonable accord with at least the more significant structures of the Paleozoics? Relations observed here where the surface of the pre-Cambrian is uncovered, may provide some guide to probable conditions farther west and northwest where the pre-Cambrian is deeply buried.

From the published areal geology maps of the Reading Prong and more especially of the Honeybrook Upland area, it appears that the pre-Cambrian mass did not remain neutral to the folding, and that the Cambrian-pre-Cambrian junction did not act as a plane of weakness, above which the Paleozoics sheared so that their major as well as minor structures became independent of the pre-Cambrian surface. Rather, the pre-Cambrian complex yielded to the forces that deformed the Paleozoics, and such yielding may have been a significant factor in development of the folds of the Paleozoics.

The most striking example in the area to show adjustment of the pre-Cambrian basement to a fold of the overlying Cambro-Ordovician strata occurs in the Mine Ridge anticline extending southwestward from the main part of the Honeybrook Upland (Fig. 5). This is a large and comparatively simple arch, in which the surface of the pre-Cambrian rocks rises in consonance with the curvature of the Cambro-Ordovician strata. The southern limb is steeper than the northern limb, so that the axial plane dips northward as it does in adjacent folds.

The near-by Welsh Mountain anticline is much disturbed by faults, so that it does not form a smooth arch. Nevertheless, the irregularity is apparently not due to special weakness and consequent shearing along the Cambrian-pre-Cambrian surface; instead, the faults causing the irregularities seem to transect the Cambrian and pre-Cambrian alike, although they are somewhat more numerous in the Paleozoics than in the pre-Cambrian. (See both map and structure section, Fig. 5.)

It is reasonably clear that in the Reading Prong and Honeybrook Upland the

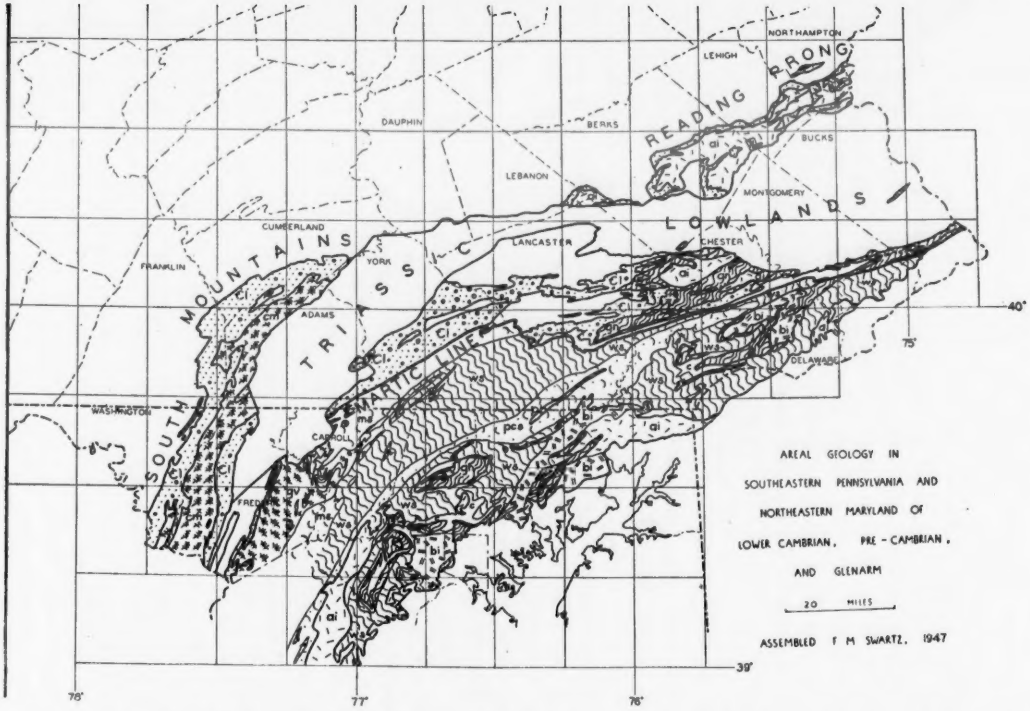

FIG. 4.—Areal geology in southeastern Pennsylvania and northeastern Maryland of Lower Cambrian and pre-Cambrian north of Martic Line, and of Glenarm and associated rocks southeast of Martic Line. Symbols are as follows, in descending order. *South Mountains:* -Cl, Lower Cambrian; cm, Catoctin metavolcanics. *Reading Prong:* -Cl, Lower Cambrian; ai, pre-Cambrian acidic intrusives, with small areas of other pre-Cambrian rocks. *Area between Triassic Lowland and Martic Line, including Honeybrook Upland toward east:* -Cl, Lower Cambrian; bi, pre-Cambrian basic intrusives; ai, pre-Cambrian acidic intrusives; gn, Pickering sedimentary gneiss. *Glenarm area south of Martic Line:* pb, Peach Bottom slate and Cardiff conglomerate; pcs, Peters Creek schist; ws, Wissahickon schist, commonly based by narrow belts of Cockeysville marble and Setters quartzite at domes of Baltimore gneiss; gv and ms, Glenarm metavolcanics and Marburg schist, respectively, with some small areas of Wakefield and Silver Run marbles, the relations to Glenarm proper not well established; bgn, Baltimore gneiss, pre-Setters: bi, and ai, post-Wissahickon basic and acidic intrusives.

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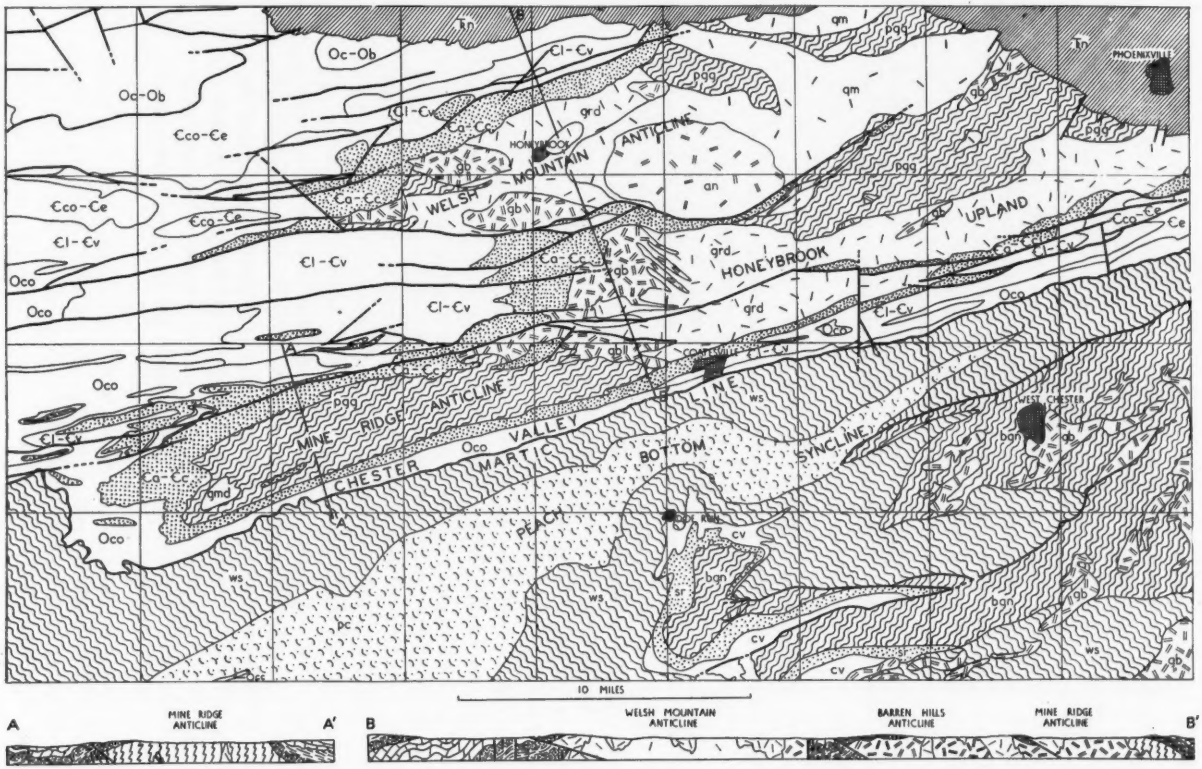

FIG. 5.—Areal geology of Trenton and sub-Trenton in Honeybrook Upland, Mine Ridge anticline, Chester Valley, and eastern part of Peach Bottom syncline, southeastern Pennsylvania. North of Martic Line: Rn, Triassic, Newark redbeds. Oc-Ob, Cocalico shale and Beekmantown limestone; Oco, Conestoga limestone; Cco-Ce, Conococheague and Elbrook limestones; Cl-Cv, Ledger, Kinzers, and Vintage dolomites; Ca-Cc, Antietam quartzite, Harpers schist, and Chickies quartzite; gb, pre-Cambrian gabbro; an, pre-Cambrian anorthosite; qm, pre-Cambrian quartz monzonite; grd, pre-Cambrian granodiorite; pgg, Pickering gneiss. South of Martic Line: Opc, Peach Bottom slate and Cardiff conglomerate; pc, Peters Creek schist; Ws, Wissahickon schist; cv, Cockeysville marble; st, Setters quartzite; bgn, Baltimore gneiss; gb, post-Wissahickon gabbro.

larger structures of the Paleozoics did not develop independently of movements in the pre-Cambrian mass; but that instead the pre-Cambrian yielded to the forces that folded the Paleozoics and may well have served to transmit a significant part of the folding stress.

These comments are not of course meant to suggest that all of the folds and faults of the Paleozoics continue into the pre-Cambrian basement. Folds and faults change form and amplitude within the Paleozoics themselves, and such changes are to be expected with some increase in approaching and crossing the pre-Cambrian surface. In the Reading Prong and Honeybrook areas, however, there is no flat-lying boundary surface at the base of the folded Paleozoics, such as that postulated for the base of Mesozoics of the Jura Mountains. The writer knows of no reason to suppose that this relationship changes in the major folds on the west and northwest.

PRE-CAMBRIAN VOLCANICS OF BLUE RIDGE PROVINCE

The South Mountains, just west of the Triassic Lowland in south-central Pennsylvania and central Maryland (Fig. 4), form the northern part of the Blue Ridge Province of the Appalachian Highlands. Various ridges and valleys are carved from a succession of 3,000–4,000 feet of arenaceous and argillaceous sediments that contains Lower Cambrian fossils near its summit. Through half or more of the South Mountains, however, the Lower Cambrian strata have been stripped away by erosion, exposing a now-metamorphosed mass of extrusive igneous flows and tuffs. Especially widespread are epidote-rich metabasaltic greenstones, named by Keith, Catoctin schist, from Catoctin Mountain along the eastern border of the South Mountain region of Maryland. Associated metarhyolites or aporhyolites are bluish gray to reddish. The metarhyolites have not been given a special formational name. Since they are, in a structural and stratigraphic sense, intimately related to and intermingled with the metabasalts, the whole volcanic terrane including the metabasalts, the metarhyolites, minor metaandesites, and thin metasediments, are with questionable license grouped for the present discussion as Catoctin metavolcanics.

The Catoctin metavolcanics in this inclusive sense are composed predominantly of modified basaltic lava flows in the present area of outcrop in Maryland, with rhyolitic flows increasing in proportionate volume along the extension of the South Mountains into Pennsylvania. Recognized andesite flows are very subordinate. Amygdaloidal blebs are found at many places. Tuffaceous deposits, some with pyroclastic fragments an inch or two in diameter, form a few per cent of the total mass.

A complex of granodiorite and biotite granite is exposed in the Catoctin belt near the Potomac River in Maryland. According to Stose and Stose (1946), the granitic complex is cut by feeder dikes of the Catoctin; hence, it is part of the basement upon which the Catoctin rocks accumulated. Margining the exposures of the granitic complex are locally identified, thin occurrences of sedimentary

quartzites and associated tuffaceous slates, which are thought by Stose and Stose to represent the initial materials of the Catoctin series; at one place there is a small body of marble at this stratigraphic position. Metabasalts adjoin and appear to rest on these metasediments, or, where the latter are absent, lie directly against the granite complex. Farther north, where the metarhyolites are plentiful, it is not clear whether the metarhyolites in general lie stratigraphically above or chiefly occur below the metabasalts. To some degree, at least, bodies of the metarhyolites and metabasalts interfinger with one another.

The whole Catoctin mass has undergone low-grade metamorphism, so that there is a pervasive schistosity that dips southeastward at an angle of approximately 60°. The same schistosity affects Lower Cambrian sediments of the South Mountains region, and hence was not produced in pre-Cambrian time (Cloos, 1940).

The metamorphic crystals of the Catoctin mass are very fine-grained. Nevertheless, there is sufficient masking of original structures so that it is difficult under the conditions of soil and forest cover to follow individual flows and to establish the succession and thicknesses of members of the mass. Judging from the areal extent of the metavolcanics, and supposing that their structural complexity is comparable with that of the adjacent Paleozoics, one may estimate that the thickness of the volcanic succession reaches a maximum of at least a mile.

Mapping in the Fairview Quadrangle (Stose and Bascom, 1929) of some minor, locally traceable divisions of the metavolcanics suggests that there is a low-angle unconformity at the contact of the lavas with the Loudoun formation at the base of the Cambrian sediments. Such erosion may explain variations in Maryland in distances across the metavolcanics from the base of the Loudoun to the plutonics believed by Stose and Stose to underlie the Catoctin. Furthermore, the Loudoun sediments at places were derived principally from metarhyolites of the Catoctin series, and elsewhere in Maryland and Virginia came largely from granitic rocks such as those associated with the Catoctin. All of these relationships suggest that there was at least local erosion of the Catoctin before and during Loudoun time. Keith (1894) thought it probable that in northern Virginia the pre-Loudoun surface of the Catoctin had a relief of 500–800 feet. Geologic maps of the South Mountains of Pennsylvania and Maryland by Stose and Bascom (1929) and Stose and Stose (1946) suggest the pre-Loudoun surface was more nearly peneplaned than it was considered to be by Keith in northern Virginia.

It is not clear that the erosional features associated with the boundary between the Catoctin volcanics and the Cambrian sediments were related to diastrophic movements of more than local significance, or that the erosional hiatus was long continued. Nevertheless, in the South Mountains of central Maryland and south-central Pennsylvania the Lower Cambrian sediments were deposited during a period that definitely succeeded the end of a period of vulcanism; except for thin tuffaceous slates of the initial Loudoun formation, the extrusive activity

of Catoctin time ceased abruptly and completely in the South Mountain area at the beginning of Lower Cambrian sedimentation. It may well be true, however, that in eastern Frederick County, east of the South Mountains, Catoctin vulcanism persisted longer and that the interbedded volcanics and sediments there classed as Glenarm represent an intergradational, earliest Cambrian stage not represented in the South Mountains.

A marked peculiarity about the relationships of the Catoctin metavolcanics is the lack of recognized basaltic material in the detritals of the Lower Cambrian Loudoun formation. Material from the rhyolitic flows occurs in abundance in some Loudoun strata in the Fairfield region (Stose and Bascom, 1929); the detrital fragments range to an inch and more in diameter in some conglomeratic layers, and finer-textured rhyolitic débris is recognizable in various slaty members. In Maryland, some of the sandy deposits of the Loudoun contain considerable feldspar along with blue quartz such as that characterizing granitic rocks of the supposed pre-Catoctin basement.

The rhyolitic materials of the Loudoun suggest that there was during Loudoun time much relatively local erosion from rhyolitic eminences of moderate elevation. Lack of observed basaltic materials is surprising in terms of the abundance of resistant metabasalt float to-day covering surfaces in the South Mountain area. Such lack might be attributed to several possible causes, such as, first, the possibility that the later extrusions were rhyolitic, and it was these rocks that formed the prominences of the Catoctin surface as Loudoun deposition was initiated. Second, under the conditions of weathering during Loudoun time, the basaltic flows, not then metamorphosed, may have decomposed to clays scarcely recognizable in the Loudoun deposits as they are examined to-day, whereas the rhyolites provided fresher, characteristic fragments. Third, the volcanic detritus included in the Loudoun deposits may largely have come from outside the area of the Catoctin exposures of the South Mountains, and if so may have been derived from uparched rhyolitic volcanics. Answers to these alternative hypotheses remain speculative at present.

The exposed pre-Cambrian rocks of the South Mountains differ markedly from the pre-Cambrian complexes of the Honeybrook Upland and Reading Prong in eastern Pennsylvania, as well as from the pre-Cambrian of the Adirondacks Mountains of New York. No volcanic sequence of Catoctin type is found in the latter areas. The pre-Catoctin plutonic complex exposed in the South Mountains is simpler than the pre-Cambrian basements known in the other areas, though its buried extensions may be equally complex.

GLENARM PROBLEM

Pre-Cambrian age of the Grenville metamorphics and their intruded plutonics in the Adirondacks is well established by their position with respect to the major unconformity below Cambrian strata, even though these contain no known faunas older than those of the Late Cambrian. Similar evidence, with position below

proved Lower Cambrian formations, assures the pre-Cambrian age of sedimentary gneisses and associated plutonics of the Reading Prong and Honeybrook Upland of eastern Pennsylvania. In the South Mountains of south-central Pennsylvania and central Maryland, Catoctin volcanics represent a large outpouring of lavas that ceased with beginning of deposition of an overlying 1-mile thickness of strata that contain Lower Cambrian faunas near their summit.

The Glenarm series, consisting of schists and some quartzites and marbles south and east of the Martic line in southeastern Pennsylvania and northeastern Maryland (Figs. 4, 5, 6), lacks such clear-cut relation with strata of paleontologically established Cambrian age. Hence, its own age, its structural condition, and its role in the stratigraphy and paleogeography of the early Paleozoics have been subjects of conflicting interpretations.

Modern studies of the Glenarm schists began near Philadelphia and Coatesville in southeastern Pennsylvania and near-by parts of Maryland. South of the Honeybrook Upland, Cambrian strata are succeeded in Chester Valley, Pennsylvania, by Conestoga limestone that in part, at least, is Beekmantown in age. The Conestoga in turn dips southward beneath albite-chlorite schists or phyllites of the South Valley Hills bordering the southern margin of Chester Valley. Areal geological features are illustrated in Figures 5 and 6.

Thirty to forty years ago, Bascom (1905–1909), Bliss and Jonas (1917), and others were in general agreement that the albite-chlorite schists of the South Valley Hills rest in sedimentary succession on the Conestoga limestone; hence, that they are Ordovician in age. The schists of these hills were named "Octoraro" by Bascom in 1909, with the comment that their contact with the Conestoga can not be a fault because of (1) the lithologic intergradation from the limestone to the schist; (2) widespread occurrence at the limestone-schist contact of a particular geodiferous bed; (3) essential parallelism of the limestone-schist contact with bedding of the limestone, even where secondary folds superimpose convolutions on the major structures.

Oligoclase-biotite schists south of the "Octoraro" belt near Philadelphia were at the same time termed Wissahickon schist by Bascom (1909), and were classed as pre-"Octoraro" and pre-Cambrian chiefly because of their more advanced metamorphism, and because they are intruded by plutonics unknown in the "Octoraro" of the South Valley Hills as well as in the Paleozoic limestones and quartzites of Chester Valley.

Near Doe Run (Fig. 5), Bliss (later Mrs. Knopf) and Jonas discovered "pre-Cambrian" Wissahickon above Setters quartzite and Cockeysville marble, and since the latter were identified with the Cambro-Ordovician quartzites and limestones of Chester Valley, it was concluded that the Wissahickon had been placed upon the Cockeysville by a major, fenstered overthrust.

The foregoing interpretations soon were greatly modified by Knopf and Jonas (1923, 1924). It was discovered that along the Peach Bottom syncline the Wissahickon plunges beneath the southern margin of the Peters Creek schist, and that

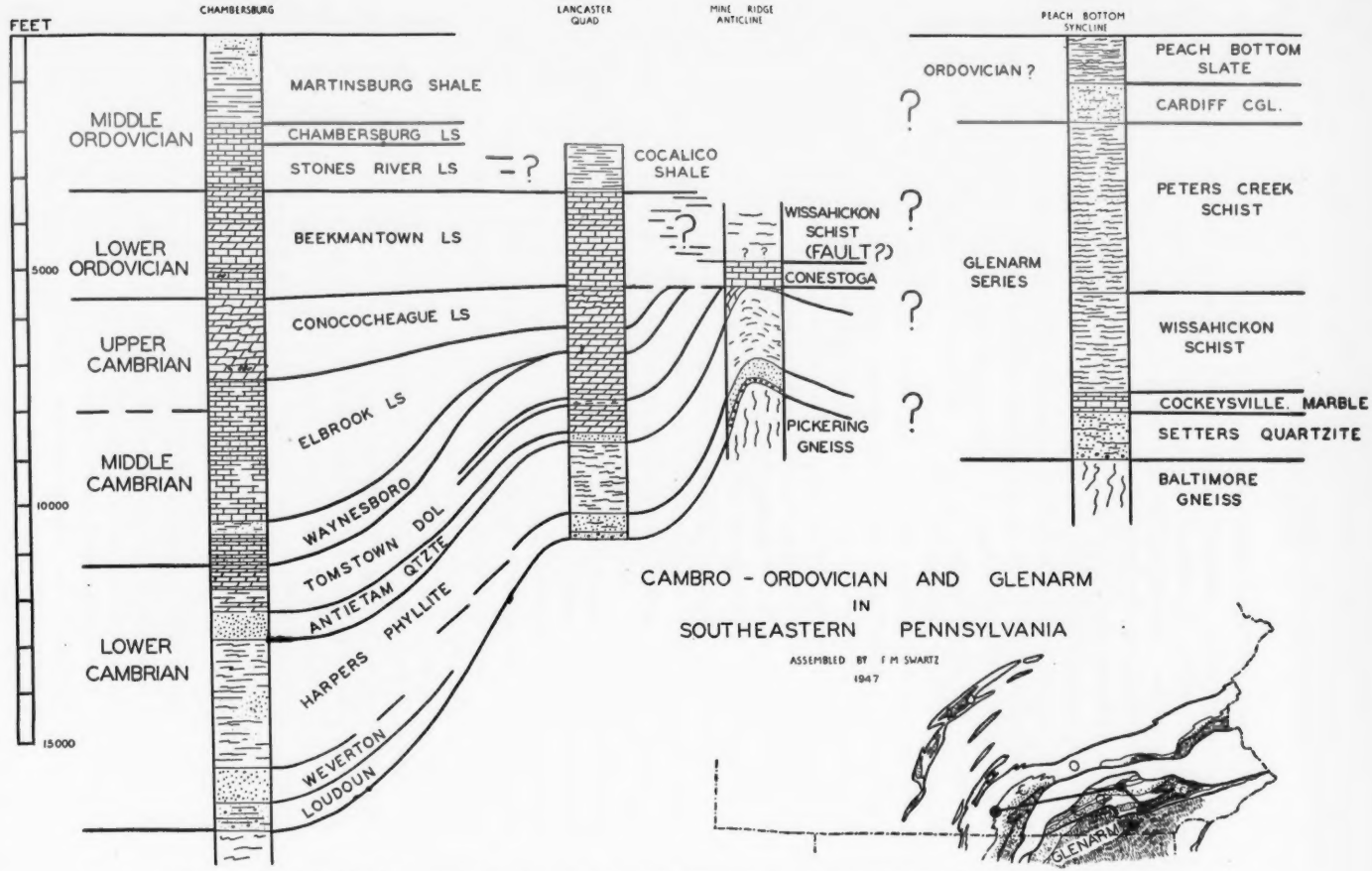

FIG. 6.—Stratigraphic chart comparing Cambro-Ordovician sequences near Chambersburg, Lancaster, and Mine Ridge, with Glenarm series of eastern part of Peach Bottom syncline.

it emerges on the northern side of the Peters Creek belt as the albite-chlorite type of schist that theretofore had been classed as "Octoraro." Knopf and Jonas hence concluded that the "Octoraro" is simply a less metamorphosed, northerly facies of the Wissahickon, and that the name "Octoraro" should be abandoned. Subsequent workers have agreed with this opinion, which may be accepted as a basic feature of the geology of the schists. Hawkins (1924), for example, placed emphasis on observable lateral intergradations near Doe Run and Avondale of the "Octoraro" and Wissahickon, and concluded that the southeasterly increase in metamorphic intensity resulted largely from increased soaking and feldspathization from acidic plutonics.

Knopf and Jonas (1923) furthermore suggested that near Doe Run and elsewhere the Wissahickon rests on the Cockeysville marble and Setters quartzite in normal sedimentary succession and not by the major fault that had been postulated in 1917.

These two generally accepted concepts of the schist structures were woven into a larger geologic pattern that has bred the vigorous controversy known as the Glenarm problem. The Wissahickon was grouped with the underlying Cockeysville and Setters formations, and overlying Peters Creek, Cardiff,[3] and Peach Bottom[3] formations, in the Glenarm series, named from a locality near Baltimore, Maryland. The Glenarm series *in toto* was classed as pre-Cambrian. This view of geologic age required postulation of a great overthrust to carry the albite-chlorite "Octoraro" facies of the Wissahickon onto the Ordovician limestones of Chester Valley; the assumed overthrust was termed Martic fault; its crop was drawn along the "Martic Line" of Figures 4 and 5; the fault subsequently was identified over a distance of several hundred miles in Pennsylvania, Maryland, and Virginia.

The crux of this structural interpretation turns upon the question of age of the Glenarm series. Assumption of pre-Cambrian age was advanced by Knopf and Jonas (1923, 1924) chiefly for the following reasons. First, the Wissahickon had "been shown to be" pre-Cambrian by Bascom in 1909 because of its intrusion near Philadelphia by gabbroic and granitic rocks that are "notably lacking" in recognized Paleozoics in adjacent areas, whereas gabbroic and granitic plutonics are found unconformably beneath Lower Cambrian strata in the Honeybrook Upland; second, according to work then in progress by Jonas, strata of probable Cambrian age occur unconformably on the Glenarm in Frederick and Carroll counties, Maryland, and in York County, Pennsylvania; third, Jonas' work in these counties further showed that the Glenarm bears volcanic intercalations closely similar to the pre-Cambrian Catoctin lavas of the South Mountains.

The views that the Glenarm rocks are pre-Cambrian, and that the Wissahickon was placed upon the Conestoga limestone of Chester Valley by a great over-

FIG. 6.—Stratigraphic chart comparing Cambro-Ordovician sequences near Chambersburg, Lancaster, and Mine Ridge, with Glenarm series of eastern part of Peach Bottom syncline.

[3] In later discussion, the Cardiff conglomerate and Peach Bottom slate have been classed tentatively as Late Ordovician and removed from the Glenarm series because Maysville fossils are found in stratigraphically comparable Arvonia slate in Virginia.

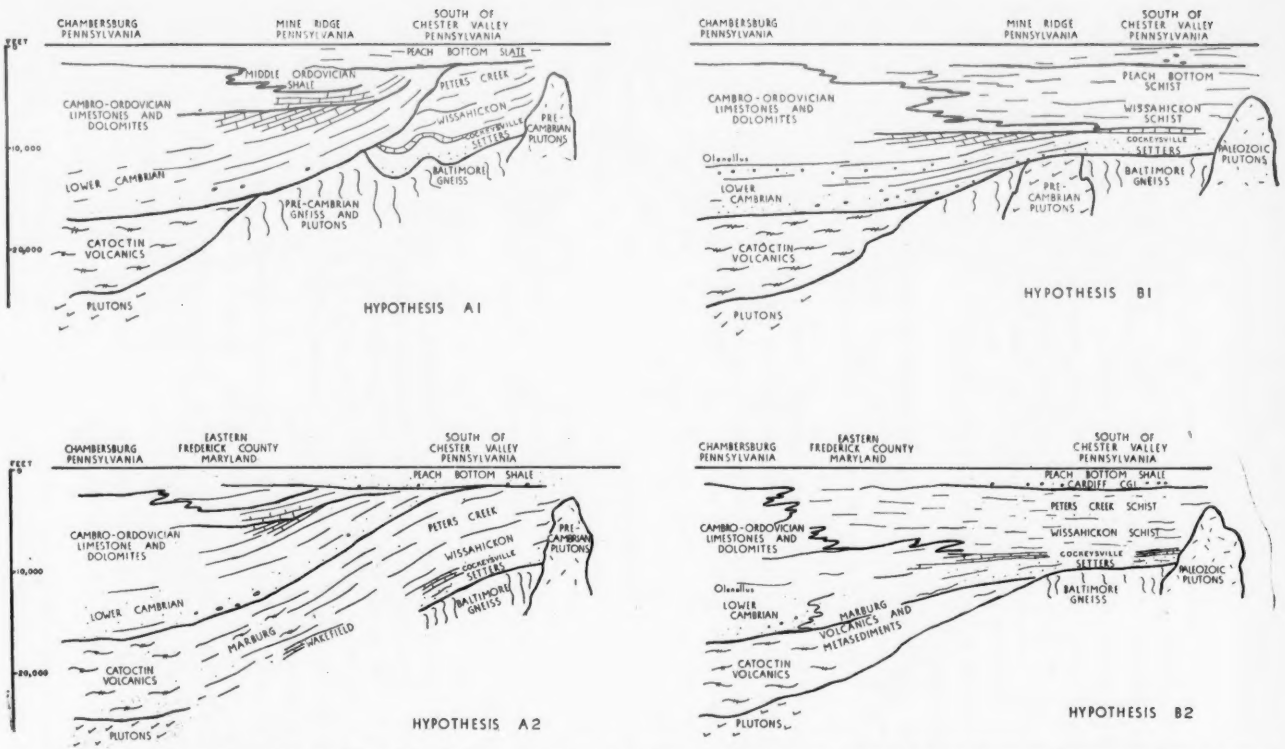

FIG. 7.—Diagrammatic sketches illustrating alternative hypotheses of Glenarm relationships. A1 and A2 are based on interpretation that typical Glenarm rocks, including Peters Creek, Wissahickon, Cockeysville, and Setters of area south of Chester Valley, are pre-Cambrian in age. B1 and B2 are constructed on alternative hypothesis that Glenarm rocks are a now-metamorphosed, more largely detrital, southeastern facies of Cambro-Ordovician of Chambersburg region. Relations of Marburg volcanics and metasediments of eastern Frederick County (A2 and B2) present special problems.

thrust, have been strongly opposed by Hawkins (1924), Malkin (1935), B. L. Miller (1935), and Cloos (1936, 1937, 1940). All of these men have favored the view that the Wissahickon of the South Valley Hills rests on the Conestoga limestone of Chester Valley with essential sedimentary conformity, and that the Martic Line is not here, at least, the line of a major belt of overthrusting.

In present review, it appears to the writer that there is much evidence favoring the opinion that the Glenarm series as developed south of Chester Valley is Cambro-Ordovician in age, and less reason for supposition of pre-Cambrian age.

Some of the alternative stratigraphic interpretations of Glenarm, Cambro-Ordovician relationships are illustrated graphically in Figure 7. Full consideration of these possible Glenarm relationships lies beyond the scope of the present discussion, and the following remarks deal with only a few of the significant problems.

Jonas has reported (Stose and Jonas, 1939; Stose and Stose, 1946) that the quartzites in Frederick and Carroll counties, Maryland, tentatively classed in 1924 as Lower Cambrian with the supposition that they rest unconformably on the Glenarm and give proof of its pre-Cambrian age, appear to belong in the Glenarm and can not satisfactorily be correlated with the Lower Cambrian quartzites of the South Mountains. Hence they are not, as was then believed, evidence of pre-Cambrian age of the Glenarm.

The original assumption of pre-Cambrian age of the Wissahickon schists rested primarily on their marked metamorphism, and their invasion near Philadelphia by plutonics that are not duplicated in the proved Paleozoics of Chester Valley, but instead are comparable with igneous bodies unconformably beneath the Lower Cambrian in the Honeybrook Upland.

With discovery that the Wissahickon changes northwestward into the albite-chlorite "Octoraro" facies of decreasing degree of metamorphism, the view that the strong metamorphism of the Wissahickon gives evidence of pre-Cambrian age began to lose force. Like the Cambro-Ordovician of Chester Valley, the more northerly part of the Wissahickon lacks intrusive plutonics, and indeed tends to be less metamorphosed than the proved Cambro-Ordovician sediments. Knopf and Jonas in 1923 called attention to the waning in metamorphic effects in the northerly Wissahickon rocks as compared with the Lower Cambrian strata of the Mine Ridge anticline, and thought this "one of the most puzzling problems of the region." It is not a puzzling problem if the Wissahickon rocks are Ordovician instead of pre-Cambrian in age.

The Glenarm succession in Pennsylvania south of Chester Valley resembles the recognized Cambro-Ordovician sequence of Mine Ridge and near-by Lancaster Valley as it begins with tourmaline-bearing quartzites, overlain by carbonate rocks and next by argillaceous deposits; furthermore, like the Cambro-Ordovician of Mine Ridge, it rests with major unconformity on an older gneiss complex. The thicknesses of these major members are significantly different in

the Glenarm as compared with the Cambro-Ordovician near Chambersburg and even near Lancaster, and the thickness changes have been cited as evidence of non-equivalence. It has not heretofore been properly emphasized that the thickness changes do no more than carry forward trends observed in the unquestionable Cambro-Ordovician sediments as they are traced from Chambersburg to the Lancaster Quadrangle and then to Mine Ridge and Chester Valley. (Fig. 6.) Whereas the supposition that the Glenarm is Cambro-Ordovician requires no more than a plausible type of facies change, such as might be expected in approach toward the source region of the Wissahickon clastics, the alternative view that the Glenarm is pre-Cambrian demands that there be a major change in rock sequence and in geologic history in the terranes immediately south and north of the Martic Line. There is no trace of a sedimentary series suggestive of the Glenarm beneath the Cambrian of the Honeybrook Upland. (Figs. 5, 6, 7.)

These lines of approach to the Glenarm problem, and other structural data as well, tend to support the opinion that the Glenarm metasediments south of Chester Valley are more probably Cambro-Ordovician than pre-Cambrian. It is desirable to recognize that the Glenarm as traced to some other regions, as in parts of Frederick and Carroll counties, Maryland, has been made to include rock groups not represented in the type Glenarm, and it does not necessarily follow that all so-called Glenarm rocks are Cambro-Ordovician even if this be true of the Glenarm south of Chester Valley. In particular, the extensive metavolcanics in eastern Frederick County pose special problems not readily resolved with present knowledge. Differing possible relationships of these volcanics are illustrated by diagrams in Figure 7.

Throughout discussion of the Glenarm problem, it must be recognized that these rocks occur under conditions of imperfect exposure, complexity of deformation, variation in intensity of deformation, original changes in lithologic characters, and lack of known fossils, so that interpretations are impeded. The valued studies of Bascom, Jonas, Stose, Knopf, and Cloos have all made major contributions to the eventual clarification of Glenarm relationships.

REGIONAL CHARACTERS OF PRE-CAMBRIAN BASEMENT AND POSSIBLE RELATIONS TO GRAVIMETRIC CONDITIONS AND APPALACHIAN DEFORMATION

Exposures of pre-Cambrian rocks in New York, Pennsylvania, and Maryland are too limited in area to allow more than preliminary guesses about regional relationships.

Present knowledge of the regional pre-Cambrian geology is summarized in Figure 8. On the northeast, in the Adirondack region, exposed parts of the pre-Cambrian consist of ancient carbonate, clay, and sand sediments that were intruded, sharded, and metamorphosed by successive basic and then more acidic plutons. Subsequently, but before initiation of Cambrian sedimentation, erosion carved this complex to a depth of thousands of feet and more probably several

miles, until the surface was reduced to a peneplane with relief ranging in some areas to possibly 300–400 feet.

Similar conditions occur southward in the Reading Prong and Honeybrook Upland of southeastern Pennsylvania, excepting that the early sediments were mostly sands and clays with few carbonates. Southeast of the Martic Line, the pre-Cambrian after exclusion of the Glenarm series consists of gneisses without certainly recognized pre-Cambrian plutons; the gneisses are thought to be metasediments.

In contrast with the geologic conditions in all of these areas, the Cambrian sediments of the South Mountains of south-central Pennsylvania and central Maryland are underlain by basaltic and acidic Catoctin lavas that, where fully developed, may be a mile or two in thickness. Just east of the South Mountains, the Catoctin series is questionably represented by volcanics of a narrow belt adjoining the Martic Line (Fig. 4). Southwestward, the Catoctin lavas extend for many miles along the Blue Ridge Province in Virginia.

Through most of the remaining four-fifths of the New York-Pennsylvania region, direct evidence about characters of the pre-Cambrian complex is lacking. A few wells drilled near the Adirondacks reached "granites," but do not greatly extend the known area of the Adirondack sequence. Several wells in western New York have also reportedly stopped in "granite," but these records are unsatisfactory because of inadequate description of the supposed pre-Cambrian material.

Significant tectonic relationships of the pre-Cambrian rocks are indicated by the known foliation features shown in very generalized fashion in Figure 8.

In the Adirondacks, the foliation planes have on the whole a dominant northeast-southwest trend. Some local variations in direction are related to the peripheries of stock-like intrusives.

The foliation in the Adirondack complex reflects pre-Cambrian and not post-Cambrian regional deformation and intrusion. Characters of the associated Cambrian and younger strata show clearly that there has been no appreciable modification of the foliation subsequent to the beginning of Potsdam sedimentation, and assumably not since some early stage in the period of erosion that culminated in the pre-Potsdam peneplanation.

The dominant foliation of the Adirondacks complex bears witness to the work, during pre-Cambrian time, of regional orogenic stresses aligned in substantially the direction that characterzied Appalachian mountain-making during a much later geologic period. The trend of the foliation furthermore is comparable with axial directions of Appalachian troughs of Paleozoic sedimentation. The geographic parallelism with pre-Cambrian foliation in the Adirondacks, and apparently also with pre-Cambrian foliation in terranes in Pennsylvania, Maryland, and New Jersey, suggests that the direction of Paleozoic trough-making and deformation was largely controlled by conditions established by pre-Cambrian, if not earlier, activities of the earth's crust.

Despite the parallelisms in direction of crustal failure, the pre-Cambrian and

FIG. 8.—Generalized structural features of the pre-Cambrian basement in outcrop areas in Pennsylvania, Maryland, and New York. Foliation in Adirondack region simplified from Buddington (1939); in northern New Jersey from Franklin Furnace and Raritan folios of United States Geological Survey; in Baltimore gneiss domes of eastern Maryland from Broedel (1937); in volcanics of South Mountains from Cloos (1940). Adirondack structures are pre-Cambrian in origin; those of South Mountains are post-Cambrian; those of gneiss domes and of northern New Jersey are believed to be pre-Cambrian with post-Cambrian modifications.

Appalachian deformations were not co-extensive. In New York, and probably in Pennsylvania, areas of pre-Cambrian metamorphism reach far west of the belt of strong Appalachian disturbance, and affected relatively more inward parts of the continental platform.

The foliation shown in Figure 8 for pre-Cambrian terranes in Pennsylvania, Maryland, and New Jersey is in part post-Cambrian, in part pre-Cambrian modified in uncertain degree by post-Cambrian activity.

The southeastwardly dipping foliation of the Catoctin metavolcanics of the South Mountains of south-central Pennsylvania and central Maryland, likewise permeates overlying Lower Cambrian sediments. The foliation is post-Cambrian in age, and probably developed during Late Paleozoic Appalachian mountain-making. Strong regional pre-Cambrian deformation did not affect the Catoctin volcanics. Lavas and other rocks not foliated by pre-Cambrian orogenies may extend below the Paleozoics west and northwest of the South Mountains, above a floor of pre-Cambrian gneissic rocks.

The Baltimore gneiss of the gneiss domes of east-central Maryland was foliated previous to deposition of the overlying Glenarm metasediments of plausible Cambro-Ordovician age. Foliation of the gneiss was later modified to some degree by the orogeny that strongly deformed the Glenarm schists. The pre-Glenarm configuration of the foliation of the Baltimore gneiss is not fully understood; it is probable, however, that the original regional trend was nearly in accord with the later direction of the axes of the Appalachian folds. Locally, the foliation of the Glenarm schists and perhaps of the Baltimore gneiss is modified along the peripheries of plutons.

Little has been published about foliation directions of the pre-Cambrian rocks of the Honeybrook Upland and Reading Prong of eastern Pennsylvania, beyond the remark that there is a northeast-southwest trend in the latter area. In the Raritan and Franklin Furnace quadrangles in northern New Jersey, foliation of pre-Cambrian rocks is a pre-Cambrian structure that strikes lengthwise the grain of Appalachian deformation, and in general dips southeastward at high angles. The foliation may have been modified in dip by the Appalachian mountain-making, but its strike probably was not greatly altered.

Another type of evidence that bears on regional structure of the basement rocks of Pennsylvania is furnished by gravimetric data. Nettleton's (1941) map of isostatic anomalies in Pennsylvania, New Jersey, Maryland, and parts of the Virginias, is especially valuable (Fig. 9).

Nettleton gives evidence that the gravity anomaly curve of his Pittsburgh-Gettysburg traverse (bottom, Fig. 9) is strongly discordant with expected depths of the base of the Paleozoic sediments; hence, he concludes that the isostatic anomalies must reflect deeper conditions.

The gravimetric features illustrated in Nettleton's map furnish a basic pattern to which the regional structures of the "basement" rocks of the area must conform; "basement" rocks in this sense may include rock masses older than those that constitute the known pre-Cambrian of outcrop belts of the earth's surface, and also may embrace various deep, unsuspected post-Cambrian intrusive masses.

The dominant feature shown by Nettleton's map is a belt-like isostatic low that extends through west-central Maryland, central and eastern Pennsylvania, and southeastern New York. This low was termed "Blue Ridge" low by Nettleton. It has been renamed "Appalachian low" in Figure 9 since it dominates the Appalachian gravimetric pattern, and furthermore is not coincident with the

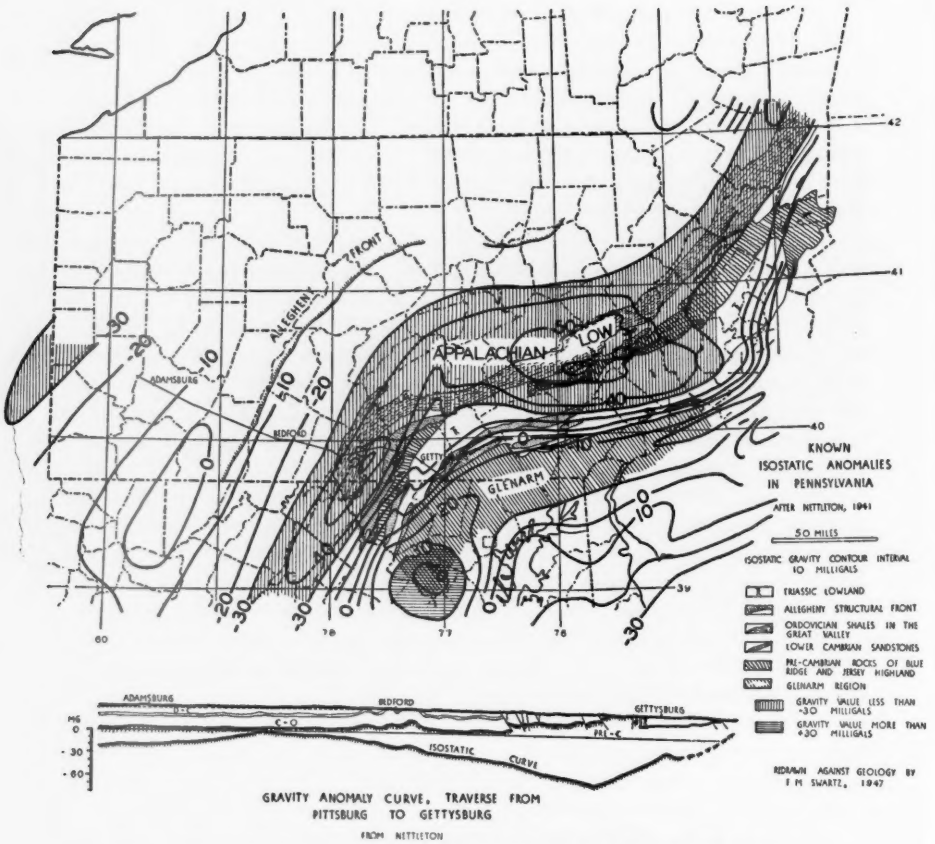

FIG. 9.—Known isostatic anomalies in Pennsylvania. Modified from Nettleton (1941).

Blue Ridge Province. In Virginia south of the map area of Figure 9, the major low parallels, but lies distinctly west of, the Blue Ridge Province. In central Pennsylvania, the axis of the low diverges markedly from the curving Blue Ridge belt, then swings eastward to the Reading Prong of the Jersey Highlands which are the northeast counterpart of the Blue Ridge. Farther north across Pennsylvania and New Jersey into New York, the axis of the low generally parallels the Jersey Highlands, but there also lies farther west.

Isostatically, the Appalachian low should mark the main root-system of the Appalachian Mountain belt.

During preparation of the present discussion, consideration was given to the possibility that the Appalachian low, especially where crossed by Nettleton's

traverse, might result from thick subsurface development of acidic phases of the Catoctin metavolcanics of the South Mountains. Several considerations make this supposition implausible. A very great development of the lavas would be required, and the widespread basaltic phases of the South Mountains area would have to be very subordinate. More importantly, the history of Appalachian sedimentation indicates that, during Paleozoic time, the region of the present-day low lay along the middle of a belt of widespread, gradual, long-continued, and

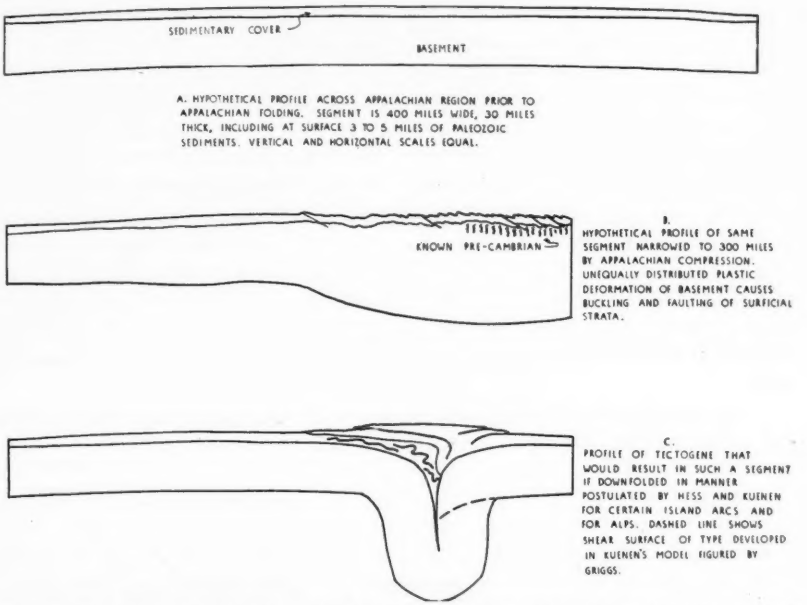
SEDIMENTARY COVER
BASEMENT
A. HYPOTHETICAL PROFILE ACROSS APPALACHIAN REGION PRIOR TO APPALACHIAN FOLDING. SEGMENT IS 400 MILES WIDE, 30 MILES THICK, INCLUDING AT SURFACE 3 TO 5 MILES OF PALEOZOIC SEDIMENTS. VERTICAL AND HORIZONTAL SCALES EQUAL.
KNOWN PRE-CAMBRIAN
B.
HYPOTHETICAL PROFILE OF SAME SEGMENT NARROWED TO 300 MILES BY APPALACHIAN COMPRESSION. UNEQUALLY DISTRIBUTED PLASTIC DEFORMATION OF BASEMENT CAUSES BUCKLING AND FAULTING OF SURFICIAL STRATA.
C.
PROFILE OF TECTOGENE THAT WOULD RESULT IN SUCH A SEGMENT IF DOWNFOLDED IN MANNER POSTULATED BY HESS AND KUENEN FOR CERTAIN ISLAND ARCS AND FOR ALPS. DASHED LINE SHOWS SHEAR SURFACE OF TYPE DEVELOPED IN KUENEN'S MODEL FIGURED BY GRIGGS.

FIG. 10.—Hypothesis of plastic deformation of Appalachian basement in relation to isostatic anomalies and to manner of deformation of Paleozoic sediments.

progressive subsidence. If control of the subsidence was isostatic, the belt should have been an isostatic high rather than low during the Paleozoic era, and in that case the present isostatic deficiency must have resulted from Late Paleozoic or subsequent crustal activity, not from pre-Cambrian events. It appears true that the present-day deep trenches of the western Pacific (Hess, 1948) are subsiding isostatic lows; however, these deep-water structures do not appear to the writer to be analogous with the Paleozoic Appalachian trough with its flood of shallow-water marine sediments and interlayered continental deposits, interrupted at many levels by surfaces of unconformity.

The present-day Appalachian low and other features of the Appalachian region of Pennsylvania can plausibly be explained by crustal shortening and

thickening of the general type illustrated in Figure 10A, B. These sketches present the hypothesis that, at the time of Appalachian folding, shortening occurred in the deep basement by widely distributed failure, here termed plastic though it assumably involved metamorphic recrystallization.

Figure 10B has been drawn to simulate the Appalachian region in Pennsylvania. Horizontal and vertical scales are equal. The basement shown in the diagram may have been complex in composition and in temperature; hence, in strength. The 30-mile depth used for the basement is no more than an approximation. Only the upper part of the basement as drawn in the sketches can be identified with pre-Cambrian rocks known at the outcrop.

The present discussion is not intended to cover the question of factors, such as distribution of stress, composition, moisture content, and temperature, that may have controlled the distribution of failure. In order to maintain analogy with the Appalachians, most of the shortening from 400 miles in 10A to 300 miles in 10B is allocated to the eastern half of the sketch. Thickening of the basement to compensate for the pervasive plastic shortening is drawn to scale. From place to place the sedimentary cover had to adapt itself to the distributed shortening within the basement; hence, buckling and faulting of the sediments are spread over a wide area, and there is no narrow axial region of abrupt net shortening of the surface of the basement such as is illustrated in Figure 10C. Minor plastic shortening on the west is reflected by small-amplitude flexures in the sedimentary cover.

The pervasive plastic shortening in 10B is favored by low effective strength, and contrasts with the more competent tectogene-type downfolding shown in 10C.

In 10B, it is not intended that the boundary between basement and sedimentary cover is a level of abrupt change in method of failure by rock flowage as compared with buckling and faulting. Instead, the change in mechanism of failure should be transitional from deep levels where flowage is predominant, to shallower levels where such failure is more and more replaced by folding and faulting.

Distribution of shortening throughout large rock masses is a well known geologic phenomenon. Quantitative data are wanting, but the foliation that pervades regional schists and gneisses may in many places represent reductions of half or more in the dimension perpendicular to foliation. Terranes to-day exposed to geologic observation show that regional metamorphism has been significant as a means of rock flowage at depths corresponding with the lower part of the sedimentary cover and higher part of the basement of Figure 10. Failure by rock flowage is plausible throughout the deeply covered basement if compressive stresses reach sufficient strength and perhaps especially if basement strengths are lowered by rises in temperature.

The tectogene hypothesis illustrated in Figure 10C has recently received favorable attention (Vening Meinesz, 1934; Kuenen, 1936; Hess, 1938, 1948; Griggs, 1941).

Judged from their form and their coincidence with isostatic lows, the western Pacific tectogene-trenches, finely illustrated by Hess (1948), may involve large scale downfolding due to tangential stress. Deepening of earthquake foci west of the trenches suggests some major type of overthrusting from the west, underthrusting from the east. It does not in any event follow that the trenches are in process of the extreme infolding shown in Figure 10C; floors of the present trench form comparatively gentle down-curves when drawn in transverse section. Distributed "plastic" rock flowage may be important at depth below the trench surfaces, especially in more advanced stages of their deformation.

Care must be used in any attempt to draw analogies between the western Pacific tectogene-trenches and Appalachian trough-sedimentation and folding. The trenches are a deep-sea phenomenon, external to the continental platform, situated along oceanic margins of the island arcs. During the Paleozoic history of the Appalachian region, the easterly lands that supplied vast quantities of detritus to the Appalachian trough may have resembled an island arc in general pattern. If so, they were very large during the periods of rapid sedimentary supply. Tectogene-trenches would be expected on their eastern, oceanic margins, not in the Appalachian region. The Paleozoic sediments of the Appalachian region suggest shallow seas spreading on a broad platform fluctuating about at sea-level, not the deep waters of the Pacific trenches.

Lower Cambrian

LOWER CAMBRIAN IN VERMONT

Recognition of Lower Cambrian strata in North America resulted from a curious sequence of geological discoveries.

The Upper Cambrian Potsdam sandstone, where it flanks the pre-Cambrian along the Lake Champlain margin of the Adirondacks, dips eastward into Vermont at a moderate angle beneath strata of Beekmantown, Chazy, and Trenton age, and the Trenton rocks in turn disappear below more deformed carbonate rocks, quartzites, and slates. The slaty rocks near Georgia, Vermont, were classed as Hudson River shale with the view that they are post-Trenton in age, by astute James Hall in 1858 when he described from them, under the name *Olenus thompsoni*, a well preserved trilobite discovered by the Reverend Zachary Thompson.

Thompsoni was subsequently made the genotype of *Olenellus*, and olenellid trilobites, it was discovered (Walcott, 1889), characterize formations in Nova Scotia and Pennsylvania well below sediments bearing faunas allied to that of the Potsdam sandstone of New York. Thus instead of having the first-supposed post-Trenton position, *thompsoni* and its olenellid relatives have been proved to be prime guides for recognition of Lower Cambrian sediments not only in Vermont, but along the whole course of the Appalachians and Rockies of North America, as well as in the British Isles, Scandinavia, and eastern Asia.

The Lower Cambrian deposits of western Vermont, as they have been made

known through the work of Walcott, Keith, and others (Cady, 1945), consist of dolomites, quartzites, and subordinate slates, totalling approximately 3,000 to possibly 5,000 feet in thickness near Burlington, Middlebury, and Brandon. The dolomites, many of them sandy, form a half to as much as two-thirds of the mass; most of the remainder consists of quartzites, of which some are white and quartzose, whereas others in the Monkton and adjacent formations of the upper part of the Lower Cambrian are reddish and are associated with thin layers and laminae of red shale. The basal Cheshire quartzite is white above, brownish, schistose, more argillaceous in its lower part; at Milton Village, E. C. Jacobs (1935) identified such rock as Brigham Hall graywacke. The slate and slaty dolomite formations of the Lower Cambrian of Vermont are best developed near the town of Georgia; but even here they are distinctly subordinate in the Lower Cambrian. Most of the slates near Georgia are Upper Cambrian in age.

According to Cady (1935), the Monkton quartzite of the upper part of the Lower Cambrian of western Vermont,

> thins northeastward, eastward, and southeastward from a center that must have been near the site of the present Adirondacks. The Parker slate and its apparent stratigraphic equivalents in the Oak Hill slice are found in about the same stratigraphic position as the Monkton, but thickening north and east of it, suggesting a source of material diametrically opposite to that of the Monkton.

The fossil faunas and, to some extent, the lithologic characters indicate that the bulk of the known Lower Cambrian sediments of Vermont were deposited under marine conditions.

LOWER CAMBRIAN IN NEW YORK

The horizon of the Lower Cambrian reaches the surface in New York in three distinct areas: namely, first, along the flanks of the Adirondacks; second, in the median to lower parts of the valley of the Hudson River; and third in the Taconic region of the more northerly part of the Hudson River Valley.

The Lower Cambrian relationships in each of these three areas are considered in turn.

LOWER CAMBRIAN RELATIONSHIPS ALONG FLANKS OF ADIRONDACKS

Where the surface of the pre-Cambrian complex intersects the present ground level along the flanks of the Adirondacks, it is overlain in general by sandstones generally classed as Potsdam formation, save where these thin out and disappear on the southwest.

Near Potsdam, at the northern margin of the Adirondacks, the thickness of the Potsdam formation is irregular, varying from approximately 100 to 300 feet. The lower part of the formation is composed of reddish feldspathic quartzites and conglomerates; higher beds are whitish vitreous, quartzitic.

The Potsdam thickens eastward, and along the northeastern margin of the Adirondacks, may attain 1,500 feet. Here the Potsdam contains in its upper third fossils indicative of Upper Cambrian age. Beneath the fossiliferous, somewhat

dolomitic quartzites and sandstones, the middle third, more or less, consists mostly of whitish, non-fossiliferous quartzitic sandstone, whereas the lowest beds tend to be reddish and feldspathic, with conglomeratic layers in which there are pebbles of quartz and quartzite, and more rarely of gneiss.

The Potsdam is primarily an Upper Cambrian formation, as is indicated by its known faunas and by its intimate-relationships to other Upper Cambrian deposits. Nevertheless, fossils have not been discovered in the lower thousand feet or so of the Potsdam along the northeastern margin of the Adirondacks, so that these strata can not be correlated by direct paleontological evidence. The marked difference of the basal reddish, feldspathic beds of the Potsdam in contrast to overlying, cleanly washed white quartz sandstone has been emphasized by several authors, and Chadwick (1919) has suggested that the whitish and reddish parts deserve separation as two distinct formations.

The relations of the lower reddish beds of the Potsdam of the northeastern Adirondack margin to the reddish Monkton quartzite of Vermont need further investigation (compare Cady, 1935). The Monkton thickens and reddens toward the Adirondacks, and forms the Red Sandrock Range just east of Lake Champlain. Southeast and east of the Red Sandrock Range, the Monkton quartzites pass laterally into sandy dolomites; northeast they pass into dolomites and slates (Cady, 1935). The Monkton in part at least is marine, and bears some marine fossils; its sands and reddish clays were brought in, it is reasonably certain, from the general area in the northeastern Adirondacks where the lower Potsdam is reddish; hence consideration must be given to the possibility that the lower Potsdam beds of that area may have been deposited as the nearer-source part of a phase of weathering and sedimentation represented in Vermont by the Monkton deposits.

In brief, Lower Cambrian sediments are absent and probably were not deposited in the Adirondack region, save possibly for the reddish sandstones at the base of the Potsdam along the northeastern margin; the Lower Cambrian age of even these sediments is speculative and unproved.

LOWER CAMBRIAN IN SOUTHERN PART OF HUDSON RIVER VALLEY

The *Olenellus* fauna of the Lower Cambrian has been discovered in the median to southern parts of the Hudson River Valley of New York in the Poughquag quartzite and Wappinger limestone, which are exposed in small areas of the Poughkeepsie, Newburgh, and West Point quadrangles (Gordon, 1911; Holzwasser, 1926; Berkey and Rice, 1921). The Poughquag quartzite is approximately 125 feet thick near Newburgh and is well cemented, resistant, whitish to yellowish. It is moderately feldspathic, but free from ferromagnesian minerals; there is some tourmaline, apatite, zircon. The Wappinger mass is a complex, that is much deformed and poorly exposed. Discovery of the *Olenellus* fauna in some beds of the Wappinger in the Poughkeepsie Quadrangle shows that those particular layers are Lower Cambrian in age, if it may be assumed that the specimens were

not carried in by reworking; but other parts of the Wappinger according to their faunas represent Potsdam, Beekmantown, and Trenton formations. The total thickness of the Wappinger sequence is believed to be of the order of 1000 feet; how much of this was deposited in Lower Cambrian time is not yet clear, though it was probably not more than a small fraction of the total mass.

LOWER CAMBRIAN OF TACONIC PLATE

South of Albany in the valley of the Hudson River there are extensive shales, that in the middle of the past century were classed *en masse* as Hudson River shale. These rocks have been proved to be a great complex, varying in age and also in their regions of deposition. Included in the shales are formations that contain the Lower Cambrian *Olenellus* faunas, whereas other parts bear fossils of Ordovician age.

The net result of stratigraphic and structural studies has been to show that there is present in the Taconic Range and near-by parts of the Hudson River Valley a plate left as a remnant of a great sheet overthrust from the east, the plate having been separated by erosion from its old root-mass. The sediments of this plate are thus exotic, and no longer lie in the area of their original deposition. From the viewpoint of paleogeography they belong in New England at some distance east of the New York border, and not in the Hudson Valley region.

The Lower Cambrian deposits of the Taconic plate include the following formations as given by Ruedemann (1930).

	Thickness (Feet)
Schodack shale and limestone, containing an *Olenellus* fauna	100–200
Troy shale, greenish and purplish, *Oldhamia, Hyolithes*	25–100
Diamond Rock quartzite	0– 40
Bomoseen grit, olive, weathering reddish	20– 50
Nassau shale, greenish, some reddish, and quartzite interbeds	100–800

The Lower Cambrian of the Taconic plate thus consists of shallow-water sands and clays with subordinate calcareous deposits in the upper part. The Schodack beds contain brachiopods and trilobites of the *Olenellus* fauna and are definitely marine. *Oldhamia* of parts of both the Schodack and Nassau is a fringed trail representing aquatic worms or possibly some type of aquatic arthropod. It is not certain that this fossil reflects a truly marine environment.

The term Schodack is now commonly extended downward to include the Troy shale, Diamond Rock quartzite, and Bomoseen grit as locally varying members. The quartzite layers of both the Schodack and Nassau were mostly deposited as rather cleanly washed, quartzose sands with minor content of plagioclase grains. The shaly parts vary from purplish to more or less reddish, but it is not certain that any of these represent a continental redbed facies comparable, for example, with the Catskill redbeds of the Devonian.

The shaly limestones of the Schodack include widespread brecciated layers. Some of these have been formed by post-depositional deformation, but in general

they seem to represent intraformational limestone conglomerates. Sparsely distributed sand grains of the limestones are largely composed of smoky quartz comparable with quartz found in rocks of the Green Mountains of New England, but not duplicated so far as known in the pre-Cambrian of the Adirondacks.

The basement rocks upon which the Schodack and Nassau accumulated, remain unknown.

GENERAL DISTRIBUTION OF LOWER CAMBRIAN IN PENNSYLVANIA AND MARYLAND

Lower Cambrian sediments are thicker and more widespread in Pennsylvania and Maryland than in New York. They are exposed in three well defined areas, as follows (Figs. 4, 12).

1. South Mountains of south-central Pennsylvania and central Maryland
2. Quartzite hills and parts of adjacent valleys in area between Triassic Lowland and Martic Line
3. Quartzite hills and parts of adjacent valleys of Reading Prong

If the Glenarm series is Cambro-Ordovician in age, as seems probable to the writer (Fig. 7), then the Setters exposures southeast of the Martic Line belong to a fourth belt, in which parts of the Cockeysville and Marburg formations likewise may be Lower Cambrian.

The Lower Cambrian strata of each of these areas are in turn briefly considered, after which attention is given to the general sedimentation and paleogeography of the Lower Cambrian of Pennsylvania and New York.

LOWER CAMBRIAN OF SOUTH MOUNTAINS

The Lower Cambrian sediments attain reported thicknesses of approximately 1 mile in the South Mountains region of south-central Pennsylvania and central Maryland. Subordinate dolomites and limestones form the upper fifth or slightly more of the sequence, but the bulk of the mass is composed of ancient sands and clays now changed to quartzites and phyllites. The great volume of the clastic material is evidence of deep erosion of the adjacent source area.

As described by Stose (1909), Bassler (1910), Stose and Bascom (1929), and Stose and Stose (1946), the Lower Cambrian of the South Mountains is constituted as follows (thicknesses are in feet).

Carbonates: 1000–1200 feet
- Tomstown dolomite (Waynesboro formation, Fig. 15, placed at top of Lower Cambrian by some authors)

Terrigenous clastics: 4000
- Antietam quartzite, 500–1000
- Harpers phyllite, 1500–2500, including Mont Alto quartzite member, 0–1000
- Weverton quartzite, 1000
- Loudoun formation, 0–500

The *Olenellus* fauna distinctive of the Lower Cambrian occurs in the Tomstown and uppermost Antietam formation. Underlying strata have furnished no fossils save worm tubes of little value for correlation. The Waynesboro formation.

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- Loudoun formation, 0–500

The *Olenellus* fauna distinctive of the Lower Cambrian occurs in the Tomstown and uppermost Antietam formation. Underlying strata have furnished no fossils save worm tubes of little value for correlation. The Waynesboro formation.

which overlies the Tomstown dolomite in the South Mountains region, is referred to the Lower Cambrian by some writers, because it seems to be continuous with part of the Rome formation of Virginia. Faunas satisfactory for correlation have not been found in the Waynesboro type deposits in Maryland and Pennsylvania.

The whole Lower Cambrian succession of the South Mountains has suffered low-grade metamorphism, so that original clayey sediments are now fine-grained phyllites, and clayey constituents of the quartzites tend to impart a less striking schistose structure.

The deformation, metamorphism, and incomplete exposure of the Lower Cambrian strata in southeastern Pennsylvania, all impede satisfactory measurements of thicknesses, and the cited values are at best only to be used as approximations. Cloos (1943) has shown that near the South Mountains some oölitic limestones have had their dimensions reduced by 50 per cent in one direction, increased by 100 per cent in another. Schistose structures likewise denote marked changes in dimensions, with maximum thickening in some direction along the plane of schistosity. It is difficult to make satisfactory allowances for these changes in dimensions. Imperfections of exposure and uncertainties about details of structure are still more troublesome, and have helped to restrict measurements to a relatively few localities. The terrigenous clastics of the South Mountains begin with the Loudoun formation, originally deposited as gravels, sands, and clays of which significant parts came from the rhyolites of the subjacent Catoctin series or at least from closely similar rhyolitic flows. In some areas, parts of the Loudoun are arkosic, with a mineral composition like that of the granitic and granodioritic plutons associated with the Catoctin. Detritus from the basaltic phases of the Catoctin has not been recognized in the Loudoun.

The Weverton quartzite, Harpers phyllite, and Antietam quartzite, overlying the Loudoun, are widely distributed and well bedded. Thc Weverton quartzite consists of well washed quartz sand, now cemented by silica overgrowths. There are some lenses of fine conglomerate. The Harpers typically is a clayey to somewhat silty clay deposit, its minerals now modified by metamorphism. As the Harpers formation is traced northeastward from Harpers Ferry at the junction of Maryland with Virginia and West Virginia, thin sandstones appear below the middle of the formation, and thicken to form the Mont Alto quartzite member which at some places forms most of the lower half of the Harpers formation. Like the Weverton, the Monto Alto quartzite consists in general of cleanly washed quartz sand, cemented by silica overgrowths. At some places the Weverton and Mont Alto are traversed by veins of milky quartz ranging upward to several feet in thickness. These evidently were formed during the Appalachian mountain making and may well have resulted from the same silica-charged solutions that produced the silica overgrowths of the quartz grains.

At its top, the Harpers formation becomes sandy and passes into the Antietam quartzite. East of Fairfield, at least, the lower part of the Antietam is decidedly graywackyish, and contains thin interlayers of pure quartz sandrock interspersed

with thicker layers of grayish impure sandstone. Parts of the non-quartz materials of the rock form irregular, discontinuous laminae extended along the direction of schistosity. Higher parts of the Antietam contain more of the purer quartz sand layers, until at the summit there are dolomitic sandstones that are sparingly fossiliferous, and that are transitional with the overlying Tomstown dolomite.

The Tomstown formation, at the top of the Lower Cambrian chiefly on the western flank of the South Mountains, is composed of limestones and dolomites, with some shaly material below the middle of the mass. It is overlain by the sandy clays, silts, and impure limestones of the Waynesboro formation.

LOWER CAMBRIAN OF AREA BETWEEN TRIASSIC LOWLAND AND MARTIC LINE

In the area between the Triassic Lowland and the Martic Line, the Lower Cambrian sediments are as measured everywhere thinner than in the South Mountains area. In general, however, there is an upper carbonate series, a lower clastic series, and the clastic series includes median Harpers clayey rocks now changed to phyllites. The reported sequences can be summarized as follows (thicknesses are in feet).

	York County		*Lancaster County*		*Chester County*
	Pigeon Hills	*Thomas-ville*	*Near Lancaster*	*Mine Ridge*	*Southwest of Phoenixville*
Upper carbonates:					
Ledger dolomite, Kinzers shale and limestone, Vintage dolomite	2,000	2.000	1,700	200–0	800
Lower clastics:					
Antietam quartzite, Harpers phyllite, Chickies quartzite with Hellam conglomerate member	2000–2,500	2,000	1,900	1,800	1,000–1,200

The Hellam conglomerate is composed of conglomeratic quartzites and phyllitic quartzites and puddingstones. In York County where it reaches as much as 500 feet in thickness, there are numerous layers bearing well rounded 2–3-inch pebbles and some 6-inch cobbles of milky quartz and quartzites, with a few pebbles of jasper. Rhyolitic fragments such as occur in the Loudoun have not been noted.

The Chickies quartzite is in general a moderately pure quartz rock, but contains some phyllites and slates. Scolithus tubes occur in some beds. The Antietam quartzite becomes phyllitic toward the east, where it is not readily differentiated from the Harpers formation.

All of the formations are increasingly affected by metamorphism in the more easterly sections. Along the flanks of Mine Ridge in Lancaster County, the Harpers formation is described by Knopf and Jonas (1923) as an albite-chlorite schist, with incipient development of biotite, and with the albite recrystallized so that its intergrowths produce spongiform individuals bearing inclusions of the other constituents of the rock. Hellam conglomerate beds of the Chickies contain crushed pebbes of granulated quartz and glassy blue quartz in a magnetite-rich, mica schist matrix.

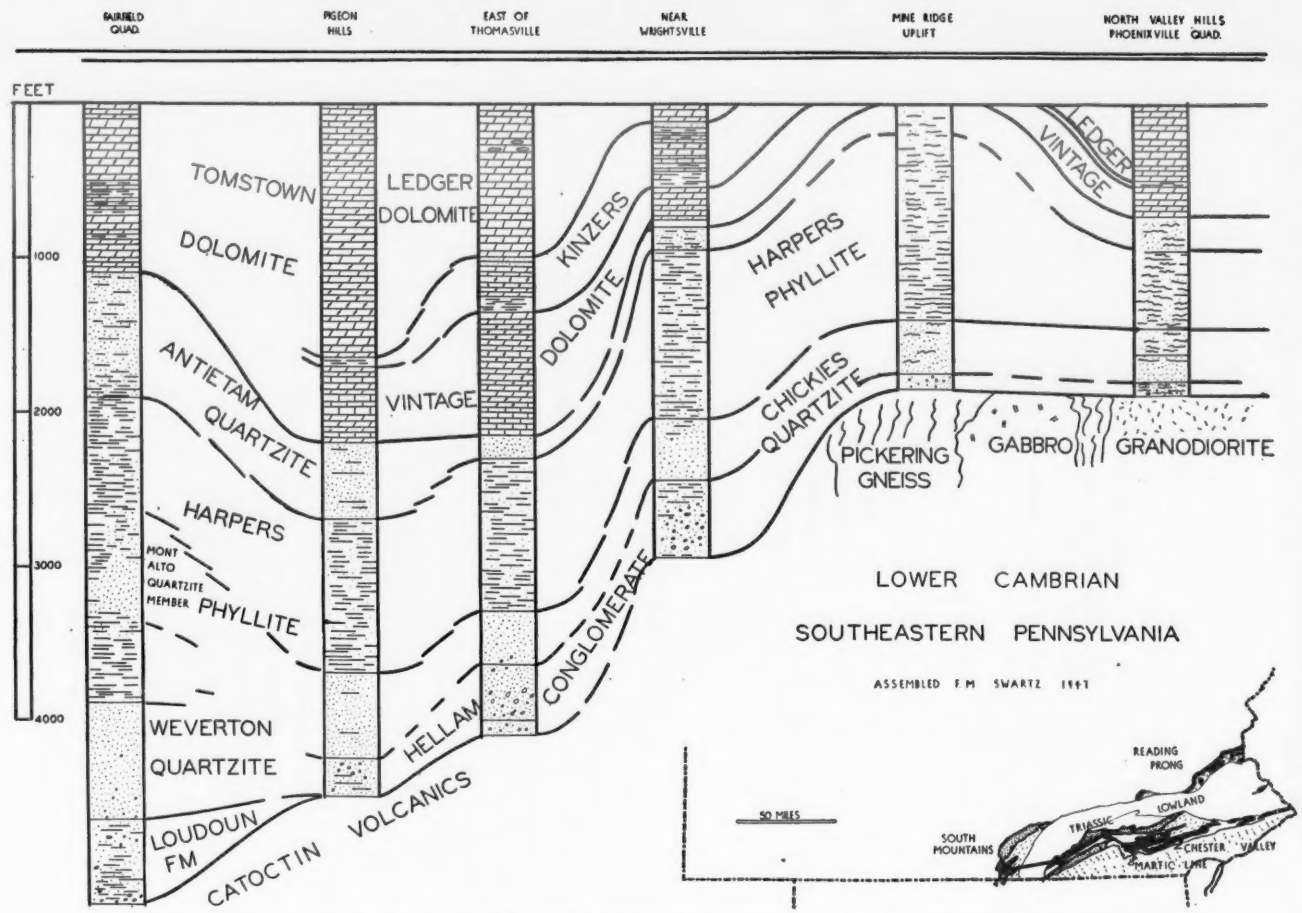


FIG. 11.—Stratigraphy of Lower Cambrian in south-central and southeastern Pennsylvania.

East of the South Mountains, the Tomstown-age dolomites first thicken to more than 2000 feet, then thin and along part of the Mine Ridge uplift wholly disappear (Fig. 11). Farther east, in the southern part of the Phoenixville Quadrangle, the dolomites again are present.

Through most of the area, the shaly Kinzers formation separates the overlying Ledger dolomite from the underlying Vintage dolomite. The Kinzers formation contains fairly numerous fragments of *Olenellus* and other distinctive Lower Cambrian fossils. Trilobites are rarer in the Vintage and Ledger, which contain some *Cryptozoön*-rich beds.

LOWER CAMBRIAN OF READING PRONG

The Lower Cambrian sequences of the Reading Prong area in Berks, Lehigh, and Northumberland counties, eastern Pennsylvania, are not illustrated in accompanying stratigraphic charts. They are essentially as follows (thicknesses are given in feet).

	Lehigh County	*Northumberland County*
Upper carbonates:		
Tomstown limestone, dolomitic and somewhat argillaceous	1,000±	1,000±
Lower clastics:		
Hardyston quartzite, some conglomerates, cherts, and arkoses	0–250	25–350

ASSUMED LOWER CAMBRIAN OF GLENARM BELT

If the Glenarm series is Cambro-Ordovician in the fashion here favored (Fig. 7B), then the Setters quartzite should be Lower Cambrian in age. Part of the overlying Cockeysville marble may also be Lower Cambrian, but judged by analogies with the Paleozoics of Chester Valley, much of the Cockeysville may be Late Cambrian or Early Ordovician.

The Setters quartzite is approximately 1,000 feet thick in the Doe Run region of southeastern Pennsylvania, and with local variations maintains this general thickness southward toward Baltimore. Parts of the Setters are vitreous, formed from cleanly washed quartz sand; parts are phyllitic and represent clayey or possibly graywackyish sand deposits. As is true of the Chickies formation of the hills bordering Chester Valley, some beds of the Setters quartzite contain needles of black tourmaline in moderate numbers.

REGIONAL RELATIONS, SEDIMENTATION, AND PALEOGEOGRAPHY OF LOWER CAMBRIAN IN PENNSYLVANIA, MARYLAND, AND NEW YORK

The characters and geographic variations of Lower Cambrian strata in the various outcrops in Pennsylvania, Maryland, and New York, briefly summarized on foregoing pages and in part illustrated in the stratigraphic chart of Figure 11, furnish data used for synthesis of the preliminary isopachous map of Figure 12, and for the interpretive stratigraphic chart and paleogeographic map of Figure 13.

None of these interpretive maps and charts can be considered fully established.

FIG. 11.—Stratigraphy of Lower Cambrian in south-central and southeastern Pennsylvania.

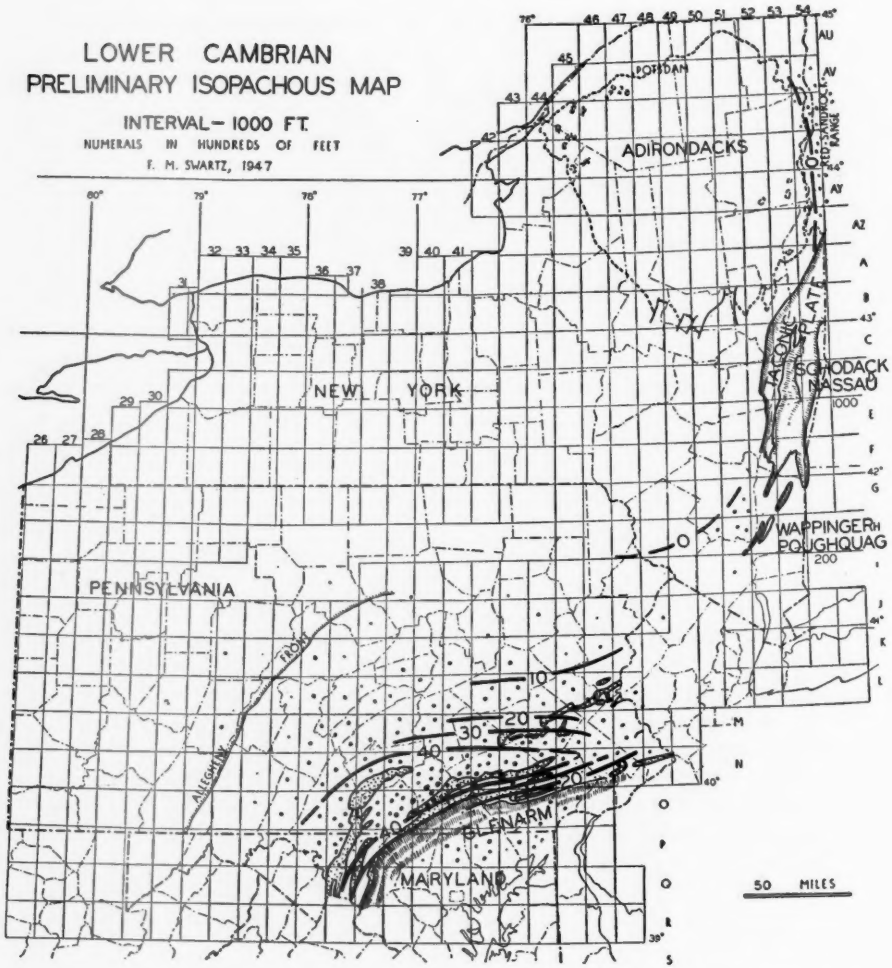
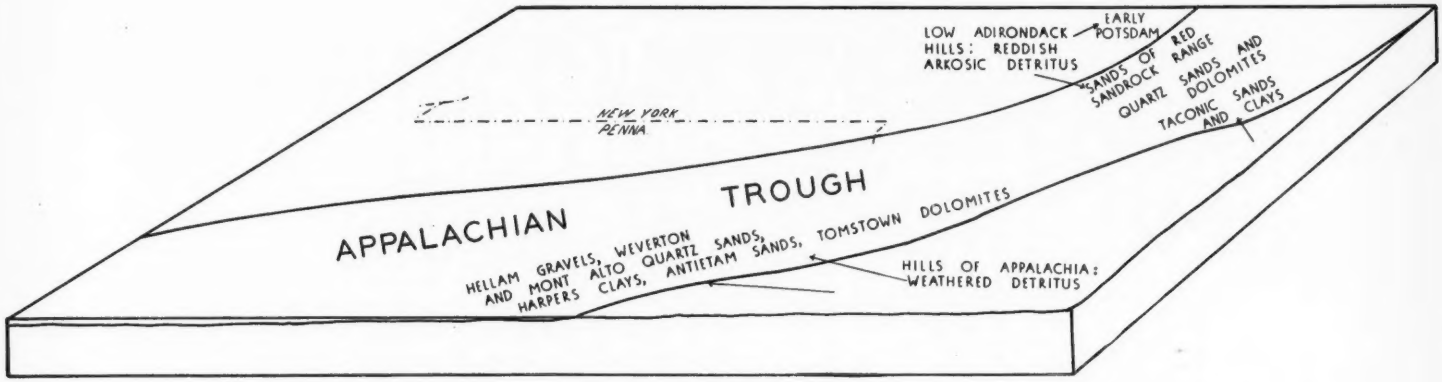


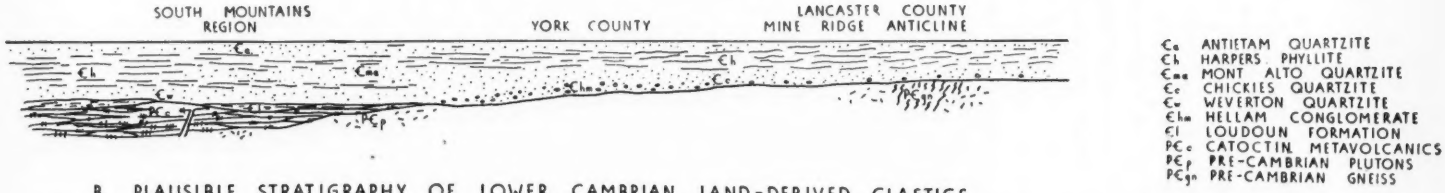
FIG. 12.—Preliminary isopachous map for Lower Cambrian in New York, Pennsylvania, and Maryland.

They express relations that seem plausible at the present stage of knowledge, but that must be subjected to further scrutiny from continued studies of regional stratigraphy and sedimentation.

Despite uncertainties about various special problems, it is reasonably clear that the Lower Cambrian sediments of Pennsylvania, Maryland, and New York


LOW ADIRONDACK HILLS: REDDISH ARKOSIC DETRITUS
EARLY POTSDAM SANDS OF RED SANDROCK RANGE
QUARTZ SANDS AND DOLOMITES
TACONIC SANDS AND CLAYS
NEW YORK PENNA
APPALACHIAN TROUGH
HELLAM GRAVELS, WEVERTON AND MONT ALTO QUARTZ SANDS, HARPERS CLAYS, ANTIETAM SANDS, TOMSTOWN DOLOMITES
HILLS OF APPALACHIA: WEATHERED DETRITUS

A. PLAUSIBLE PALEOGEOGRAPHY OF LOWER CAMBRIAN SEDIMENTATION AND SOURCE AREAS OF LAND-DERIVED CLASTICS. ARROWS SHOW DIRECTIONS OF SEDIMENTARY TRANSPORT.



B. PLAUSIBLE STRATIGRAPHY OF LOWER CAMBRIAN LAND-DERIVED CLASTICS, FROM THE SOUTH MOUNTAINS REGION TO YORK AND LANCASTER COUNTIES, PENNSYLVANIA.

FIG. 13.—Plausible paleogeography of Lower Cambrian sedimentation in New York, Pennsylvania, and Maryland, with interpretive stratigraphic chart for Lower Cambrian terrigenous clastics of south-central and southeastern Pennsylvania.

were deposited in an elongate trough, trending northeast-southwest in about the manner shown in Figure 13, and that thicknesses have essentially the trends indicated in Figure 12. The axis of maximum thickness of sedimentation traverses central Maryland, crosses southeastern Pennsylvania, northern New Jersey, and southeastern New York, and extends into northwestern New England. Thicknesses change along the axial line, so that there is a marked reduction from central Maryland and south-central Pennsylvania toward southeastern New York.

The axis of maximum thickness of the sediments should not be interpreted as the axis of maximum depth of water. The two probably did not coincide at most times, and it is probable that the greatest thickness of sediments and of greatest downwarping lay toward the area of erosion.

Insofar as marginal parts of the sediments were non-marine, the margins of the trough of deposition and of the associated seaway were not coincident at any particular time. Such sediments as the Hellam conglomerate, in particular, may well have been the deposits of a delta plain rather than sea deposits.

Throughout the trough area, Lower Cambrian sedimentation in general began with sands, clays, and some gravels, representing a period during which neighboring lands were at best moderately elevated and were undergoing fairly rapid denudation. Some red-stained detritus accumulated in the Vermont area, and subordinate purplish and some reddish beds occur in the shales of the Taconic plate. Reddish sediments are rare or absent elsewhere.

In the later part of Lower Cambrian time, erosion was less active in the lands bordering the trough, and there was widespread accumulation of carbonate rocks that chiefly are dolomites. In the Vermont region, at least, dolomites deposited toward the median part of the trough interfinger toward the margins with clayey and sandy sediments deposited toward the marginal regions.

The geology of the Adirondacks and New England shows that there, during Lower Cambrian time, the western margin of the Appalachian depositional trough trended north and south and lay just east of the Adirondack area. Deposits formed near the median part of the trough are dominantly dolomites and reach maximum thicknesses of 3000 to possibly 5000 feet. Fossils of the *Olenellus* fauna occur at several horizons, and give evidence that the waters generally were marine. Sandy, in part sparingly feldspathic detritus was brought into the trough from hills of the Adirondack region on the west. Many of these sandy sediments are whitish to grayish, and commonly the sands are relatively quartzose excepting some local graywacke near the base. Some sands of the higher part of the Lower Cambrian of Vermont, however, are stained with reddish clay. These contribute chiefly to the Monkton formation that extends eastward from the Red Sandrock Range with decrease and final disappearance of thin reddish sand and silty tongues or stringers, and concomitant increase of the dolomite interbeds. Some of the lower reddish, feldspathic parts of the thick Potsdam beds of the northeastern flank of the Adirondacks may represent near-source, alluvial-lagoonal phases of the partly marine Monkton sediments.

In northern Vermont some slates occur in the Lower Cambrian. The manner in which they interfinger with the dolomitic facies indicates that the slate formations represent clays derived from the eastern rather than from the western margin of the depositional trough. Although reddish clays stain the Montkon sands, the detritus from the Adirondack hills is not known to have supplied the volume of clayey sediments that would be expected if it came from a thick soil cover being renewed by deep weathering. At the same time, the detrital sediments do not contain the abundance of feldspar that would be expected from simple mechanical erosion of the pre-Cambrian plutons that should have dominated the Early Cambrian erosional surface of the Adirondack region.

The 1000 feet or so of clayey and sandy Schodack and Nassau sediments of the Taconic plate near Albany, New York, were deposited many miles east of their present, overthrust location. Their structural relations, the presence in the upper calcareous beds of sand grains of smoky quartz similar to types known in pre-Cambrian rocks of New England but not of the Adirondacks, and perhaps the proportion of shale, suggest that these sediments were derived from lands east and not west of the depositional trough.

The upper, more calcareous part of the Lower Cambrian of the Taconic plate contains brachiopods and trilobites of the *Olenellus* fauna and definitely is marine. Lower beds contain the trail-fossil, *Oldhamia*, that may represent bottom-crawling worms or arthropods of shallow bodies of water, though these were not necessarily the normal marine waters of the open ocean of Lower Cambrian time. The Nassau and Schodack contain subordinate purplish and some reddish shales but even these as now known are not provably of continental type.

The calcareous beds of the Schodack include extensive intraformational limestone conglomerates, likely representing broken up and redeposited, mud-cracked lime-clays of tidal flats. In underlying parts of the sequence there are numerous alternating interbeds of shale or slate and quartzite. Detritus brought in from the easterly source area included well weathered sand and clay materials, that underwent sorting and separation in the basin of deposition by action of wave agitation and currents. The detritus may largely have come from weathering of pre-Cambrian sediments or metamorphosed sediments, though there is sufficient plagioclase to suggest that some of the parent rocks were igneous. Somewhat more clay than sand reached the area of Schodack and Nassau deposition, and persistent interbedding of the sands and clays shows that there was continuing, evidently mixed supply of the two phases of detritus.

Some of the quartzite beds are coarse-grained, and a few of them are finely conglomeratic. Pebbles more than a half-inch in diameter are, however, very rare.

Unlike the Nassau and Schodack of the Taconic plate, the Poughquag quartzite and basal, Lower Cambrian part of the overlying Wappinger limestone of the Hudson River Valley, were deposited in their present region of occurrence. These sediments are thin, and in view of their own characters as well as because of the

trend of the trough farther north, probably lie fairly close to the northwestern shore of the Early Cambrian trough. The neighboring zero line of the Lower Cambrian sediments has been located in Figure 12 on this basis.

In the Newburgh area, the Poughquag quartzite is 100–200 feet thick. Its sands are relatively clean and quartzose; they contain a small percentage of feldspar but ferromagnesian minerals are very rare.

The *Olenellus* fauna occurs in the basal part of the Wappinger limestone, and gives clear proof both of Lower Cambrian age and of marine environment. Higher parts of the Wappinger contain Upper Cambrian and Early to Middle Ordovician fossils.

In southeastern Pennsylvania, the Lower Cambrian sediments, and more especially the land-derived clays and sands, first thicken and then thin somewhat as they are traced from their more northerly to more southerly exposures. These changes provide the basis for outlining the isopachous trends sketched in Figure 12, and for establishing the direction of the axis of the Appalachian trough of downwarp and deposition. Along the axis, the clastic sediments thicken southwestward, reaching reported values of approximately 4000 feet in the South Mountains region of south-central Pennsylvania and central Maryland.

A considerable amount of information about the pattern of textural and facies changes has been accumulated in the past 35 years, and in part is illustrated in Figure 11 by means of comparisons of described local sections. The same changes are illustrated in more interpretive fashion in the lower part of Figure 13, and are involved in construction of the isopachous and paleogeographic maps of Figures 12 and 13, respectively. Geographically, gravels from the adjacent source lands reach greatest development in York County, as is illustrated by Figures 4 and 11, taken in combination. The line of the sections of Figure 12 and lower part of Figure 13, extends obliquely to the axis of the Appalachian trough, not directly across it. In considering the pattern of textural changes in relation to paleogeography and conditions of deposition, it is necessary to remember that the sediments are not believed to have been transported along the line of these charts. The western sections lie near the axis of the trough where maximum thicknesses were attained. More eastern sections are south of the axis of maximum thickness and so perhaps are closer to the southeastern margin of the basin of deposition. The sections from central York County to the more northern part of the South Mountains seem more nearly to represent the direction of sedimentary transport.

Giving first attention to the terrigenous clastics in southeastern Pennsylvania and central Maryland, one finds that clays and sands are subequal in volume in the areas of exposure, although clays may be predominant farther west where the Lower Cambrian sediments extend beneath younger strata.

Clayey parts of the Harpers of Maryland interfinger with the cleanly washed quartz sands of the Mont Alto quartzite of Pennsylvania, that is believed by Stose

and Jonas to grade farther east into the Chickies formation. Both the clayey and sandy formations preserve the good bedding of water-laid deposits, excepting where masked by easterly increase in metamorphism. The volume and proportions of clay and sand, and the manner of interfingering, suggest that separation of the two facies was largely accomplished in the basin of deposition by active sorting of clayey sands and sandy clays discharged by rivers draining the bordering source lands. Because the Weverton and Mont Alto sands are quartzose and cleanly washed, even though much of the Harpers clays are silty or arenaceous, it is plausible that the sand winnowing took place in shallow reaches of the seas, where wave agitation and current movements were effective in terms of rate of influx of detritus.

Although the bedding and extent of the Weverton-Harpers-Mont Alto sediments, and cleanliness of the quartz sand suggest accumulation in extensive bodies of water, the sediments have furnished no fossils of shelly marine animals. A significant possible factor in such lack of marine shells is freshening of waters where seas spread on continental surfaces are poorly connected with the open ocean, reducing tidal and current influx of marine waters in comparison with inflow from rivers. Under present conditions, fresh water reportedly extends during calm weather for some miles to sea off the the mouth of the Amazon, and a fresh-water "shadow" occurs along the western side of the Mississippi delta. Smaller rivers might have had much greater effect in the shallow Paleozoic waters of the Appalachian region, wherever connections with the open oceans were especially imperfect.

Like the Weverton and Mont Alto, much of the Chickies formation consists of vitreous quartzites that originated as cleanly washed, water-spread quartz sand. Some parts of the Chickies, however, were deposited as clays and clayey sands.

The Hellam conglomerate, which rests on the pre-Cambrian surface as the basal member of the Chickies formation in parts of York and Lancaster counties, contains pebbles and in some places 6-inch cobbles of milky quartz, quartzites, and jasper. Published photographs suggest that the pebbles and cobbles tend to be rounded rather than shingle-like. The matrix commonly is impure, phyllitic, originally clayey or graywackyish sand. It is plausible that many of these poorly cleansed, conglomerate and cobble deposits, along with some of the associated clayey and sandy sediments, accumulated in delta plains of streams flowing swiftly from neighboring uplands.

In the South Mountains region, the varying rhyolitic and granodioritic detritus of the basal Cambrian Loudoun sediments gives evidence of local erosion and deposition. It is probable that this was accomplished by streams working on the uneven surface of the Catoctin volcanics and associated, exposed granodioritic plutons.

Detailed correlations of the changing textural facies of the Lower Cambrian terrigenous clastics of southeastern and south-central Pennsylvania are not well

enough established to fully resolve questions about location of source lands and directions of sedimentary transport.

In the South Mountains in central Maryland and south-central Pennsylvania, the Mont Alto quartzite thickens northeastward, replacing an increasing proportion of the clayey sediments of the Harpers formation and giving some suggestion of a northerly land source. On the other hand, the Weverton-Mont Alto sands of the South Mountains of Franklin and Cumberland counties, Pennsylvania, are believed to pass eastward into the Chickies quartzite and Hellam conglomerate. The Hellam conglomerates reach their greatest thickness, and develop the coarsest gravel and cobble beds, in the middle part of York County, east of the South Mountains (for geography see Fig. 4), and this change suggests derivation from land areas southeast of the Appalachian trough. The gravel and cobble beds again become less conspicuous in the still more southeastern exposures; but in view of thinning of the Lower Cambrian detritals it is reasonable to suppose that here the base of the Lower Cambrian is transgressive, and the gravel beds are reduced by unconformity. On the other hand, the disappearance of the gravel beds from York County to the thick Lower Cambrian of the South Mountains seems to be by lateral gradation into finer-grained sediments that are equivalent in age.

The net result based on the relationships as now understood, seems to favor the view that the bulk of the Lower Cambrian gravels, sands, and clays in south-central and southeastern Pennsylvania came from source lands southeast of the Appalachian trough.[4] It furthermore appears that there was a path of major sedimentary transport directed toward the York, Cumberland, and Franklin County region, so that maximum thickness of sediment and coarsest cobbles were carried into that area. Lesser volumes of the detritals reached the trough in the more easterly part of Pennsylvania (compare Fig. 12). At the summit of the detritals, the Antietam sands are likewise best developed toward the South Mountains.

If it is correct that the Glenarm series is Cambro-Ordovician in age and not pre-Cambrian, then the Setters quartzite should represent the thinning, transgressive, near-source wedge of the Lower Cambrian detritals.

The dolomites at the summit of the Lower Cambrian in south-central and southeastern Pennsylvania undergo some variations in thickness, but are persistent excepting at the Mine Run anticline (Figs. 5, 11). Their failure at this locality is due to Cambrian activity of the Mine Ridge dome. It is plausible though not wholly certain that the Lower Cambrian dolomites were deposited over this dome, and then upwarped and eroded before deposition of the Early Ordovician Conestoga limestone. Similar Cambrian dome-activity may account for some of the local absences of the Setters quartzite, as at some of the Wissahickon-Baltimore gneiss boundary surfaces east and southeast of Doe Run, Pennsylvania (Fig. 5).

[4] Further information will, however, be required to preclude possibility of major transport from the north across the northeastern part of Pennsylvania, toward the area of coarsest and thickest Hellam conglomerate (Fig. 12).

MIDDLE AND UPPER CAMBRIAN

OUTCROP AREAS OF MIDDLE AND UPPER CAMBRIAN SEDIMENTS IN NEW YORK, PENNSYLVANIA, AND MARYLAND

The horizon of the Middle and Upper Cambrian sediments reaches the surface in New York, Pennsylvania and Maryland chiefly in the following areas (Fig. 16).

1. Flanks of Adirondack Mountains in northeastern New York, together with small outliers in Adirondacks
2. Hudson River Valley (not detailed in Fig. 16)
3. Limestone valleys in central Pennsylvania
4. Chambersburg and Hagerstown areas of Great Valley of south-central Pennsylvania and central Maryland
5. Southeastern Pennsylvania east of Chambersburg
6. Glenarm region in southeastern Pennsylvania and northeastern Maryland

Characters of the Middle and Upper Cambrian sediments of each of these areas are summarized, and consideration is given to the regional relations, sedimentation, and paleogeography.

MIDDLE AND UPPER CAMBRIAN ALONG FLANKS AND IN SMALL OUTLIERS OF ADIRONDACK MOUNTAINS

GENERAL RELATIONS

The Potsdam sandstone, which rests upon the eroded surface of the pre-Cambrian complex in the Adirondack region (Figs. 14, 16), was named by Emmons (1838) more than a century ago from exposures near Potsdam in St. Lawrence County, at about the mid-length of the northern margin of the Adirondack Mountains. The sandstone was subsequently traced westward to its wedge-out south of Theresa, near the northeastern tip of Lake Ontario. Eastward, the Potsdam formation persists along the northeastern, eastern, and southeastern flanks of the Adirondacks, until on the southern margin it again wedges out between Saratoga Springs and Little Falls.

In all regions of their occurrence, the Potsdam sandstones are overlain by dolomites, or dolomitic limestones and limestones, in part somewhat sandy, that were termed the "Calciferous" by earlier geologists of New York. The "Calciferous" as a whole is Lower Ordovician Beekmantown in age. Near Saratoga Springs on the southeastern margin of the Adirondacks, however, fossils found in interbedded dolomites and limestones near the junction of Potsdam and "Calciferous" include the dicellocephalid trilobite, *Tellerina hartii*, and other distinctive Upper Cambrian fossils. These fossiliferous, in part somewhat sandy strata were grouped by Walcott with the subjacent Potsdam in the "Saratogan" or Upper Cambrian series. "Saratogan" fossils are also known in somewhat calcareous beds of the upper third of the Potsdam at Ausable Chasm, farther north along the eastern flank of the Adirondacks.

The *Tellerina hartii* limestone at Saratoga Springs has been named Hoyt limestone by Ulrich and Cushing (1910). It is commonly regarded as a local de-

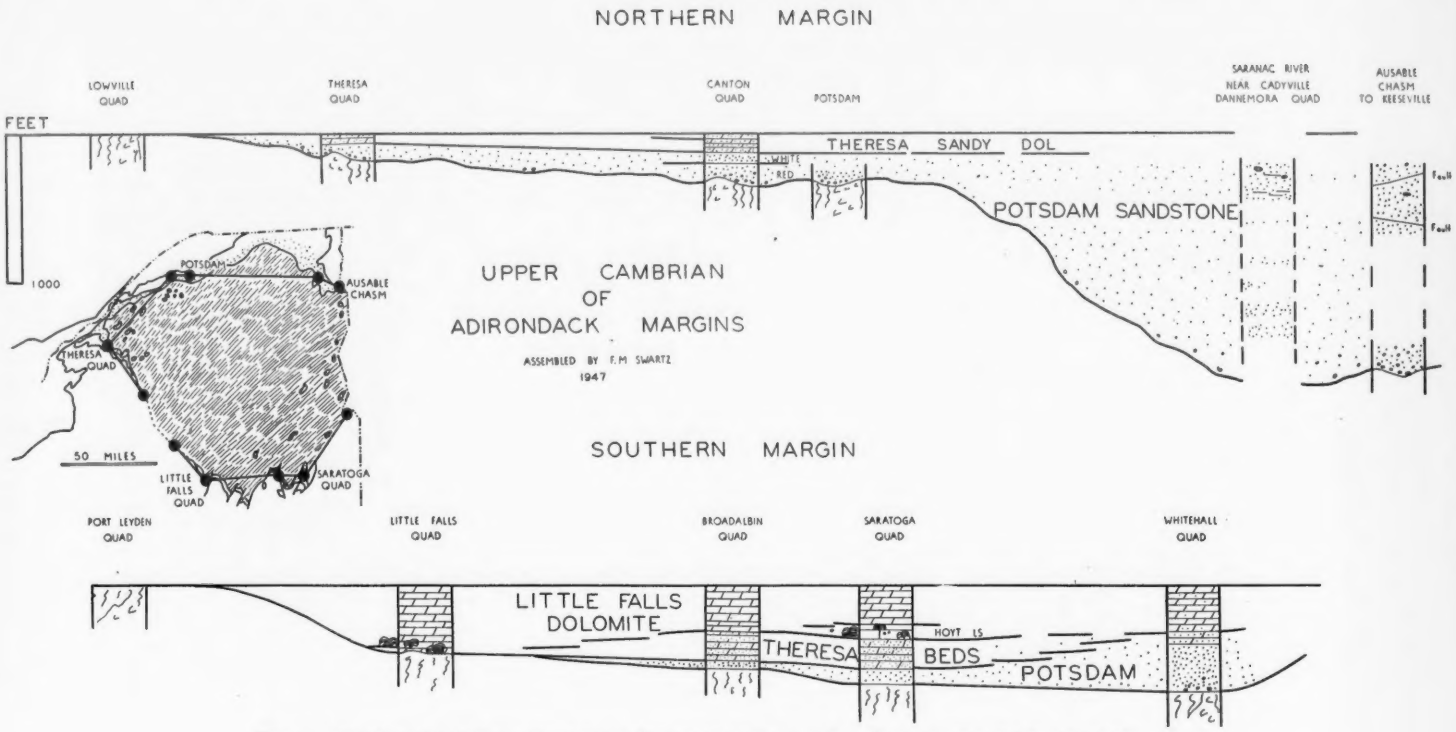


FIG. 14.—Stratigraphy of Upper Cambrian sediments of northern and southern margins of Adirondack Mountains.

velopment in the lower part of the Little Falls dolomite, which is overlain by the sandy Tribes Hill dolomite of early Beekmantown age. Between the Hoyt limestone and Potsdam at Saratoga Springs are sandy dolomites classed as Theresa dolomite by analogy with the type Theresa beds diametrically across the Adirondacks.

The Cambrian rocks of the Adirondack margins thus include, on the north and northwest, the type Theresa dolomite underlain by the type Potsdam sandstone. On the southern margin the type Little Falls dolomite, with its local Hoyt limestone member, is underlain toward the east by sandy Theresa dolomite beds and Potsdam sandstone. The characters of the Potsdam sandstone and of the overlying dolomitic rocks are discussed in turn.

POTSDAM SANDSTONE AND FORM OF PRE-POTSDAM SURFACE

In the vicinity of Potsdam and nearby Canton, northern New York, the Potsdam sandstone ranges to as much as 200 or 300 feet in thickness (Reed, 1934; Chadwick, 1919). Chadwick especially has called attention to marked differences in the upper and lower parts of the Potsdam in its type area. The upper half or so of the formation consists of cleanly washed whitish quartz sandstones or quartzites (Fig. 14). Ripple marks, largely of oscillation type, are relatively common. In marked contrast, the lower beds tend to be feldspathic, pebbly, and are stained red by iron oxide. Pebbles and cobbles of these lower strata consist predominantly of milky quartz and Grenville quartzite, but locally include fragments of granite. According to Chadwick, the basal contact commonly appears to represent a residual, reddish soil, although at other places the contact is sharply defined.

It is the reddish, conglomeratic facies that occurs along the river exposures just south of Potsdam, and so Chadwick has questioned the desirability of extending the term, Potsdam formation, to include the higher, white sandstones. He suggested that the whitish quartzose sandstone might well be distinguished as Keeseville sandstone, named for Keeseville near Ausable Chasm. The quartzose beds, however, typify the Potsdam sandstone as described in the literature.

Both the lower reddish and upper whitish members of the Potsdam vary markedly in thickness in the Potsdam and Canton quadrangles. The irregular distribution seems primarily to result from deposition of the sediments on a surface of moderate relief, in which valleys ⅓ mile to several miles in width were separated by divides rising as much as 100–200 feet above the valley floors.

Westward toward Alexandria and Theresa, in the Thousand Islands region of New York, the Potsdam sandstone consists chiefly of the whitish, quartzose, ripple-marked facies. Here likewise the Potsdam was deposited on a surface of moderate relief, with divides rising about 100 feet above the valley floors so that the formation thickens and thins in accordance with the topography of the subjacent surface. Some at least of the pre-Potsdam valleys are entrenched in the Grenville limestones. Initial dips of 20–30°, somewhat heightened by differential compaction, occur at places near the slopes of buried hills. Pebble beds are vari-

able in occurrence. Some types may represent old stream channels; others may belong at the foot-regions of sea-cliffs. The pebbles and local cobbles consist mostly of milky quartz; at some places the Grenville quartzites are well represented; fragments of Laurentian granite are common at only a few localities.

South of Theresa, the Potsdam sandstones thin and disappear, and are absent for nearly 100 miles where the pre-Cambrian surface dips beneath the Paleozoics of the southwestern flank of the Adirondacks.

Eastward from Potsdam the Potsdam thickens to 1,000 or possibly 1,500 feet along the northeastern Adirondack margin. Here also there are, in general, lower reddish and feldspathic sandstones and conglomerates, overlain by whitish quartzites, and then by calcareous or dolomitic sandstones. Near Ausable Chasm the lower beds include coarse conglomerates and red conglomeratic sandstones containing quartz, quartzite, and gneissic fragments, that were deposited on a surface with several observed ridges and bosses of anorthosite. The conglomerates are overlain by reddish, feldspathic sandstones of finer grain. Overlying beds exposed in the chasm consist of cleaner quartzose sand, in part quartzitic, in part somewhat calcareous and containing scattered pebbles of dolomite and shale. Fossils are moderately common through at least 100 feet of the calcareous strata, and include some trilobites together with *Lingulepsis acuminata* and other phosphatic brachiopoda.

Farther south, the Potsdam deposits thin once more, and are approximately 400 feet in thickness near Whitehall, 100 feet near Saratoga Springs. As near Theresa on the northwest margin of the Adirondacks, the thinned Potsdam on the southeast near Saratoga Springs consists mostly of the whitish, quartzitic facies. Westward from Saratoga, the Potsdam wedges out and disappears before reaching Little Falls.

About a half-dozen outliers of the Potsdam sandstone have been discovered in the southeastern part of the Adirondacks, a dozen or more in the northwestern region. In the southeast, a few of these small, isolated patches are 15–25 miles from the flanking Potsdam outcrops. The known occurrences represent the whitish, quartzose facies of the formation. They occur to-day in deep valleys of the mountain region. It is difficult to be certain whether they have been lowered in downfaulted blocks, or occur as remnants in the floors of ancient, deep pre-Potsdam embayments.

THERESA AND LITTLE FALLS DOLOMITES AND HOYT LIMESTONE

The Theresa dolomite, where it lies above the Potsdam sandstone along the northwestern and northern borders of the Adirondacks, ranges from approximately 30 to possibly 100 feet in thickness. It consists throughout of dolomites and sandy dolomites, with thin interbeds of sandstone. Near Canton, a 25-foot body of sandstone at the top of the Theresa was recognized by Chadwick as Huevelton sandstone. It is a locally mappable horizon, but represents little change in sedimentary conditions.

Across the entire northern border of the Adirondacks, the Theresa beds are recognized by their characteristic "sand crystals." On the broken surface of the rock, lustrous curved cleavage faces of $\frac{1}{2}$-inch crystals of dolomite are speckled with sparse, embedded grains of quartz sand.

The phosphatic brachiopod, *Lingulepsis acuminata*, has been discovered in Theresa strata at some localities in the Thousand Islands region. In general, however, fossils are rare and poorly preserved.

The Theresa dolomites are transitional with the underlying Potsdam sandstone. The uppermost Potsdam beds are dolomitic and grade into the sandy dolomites of the Theresa formation.

The uppermost 20–30 feet of sandy dolomite included in the Theresa formation, when it originally was defined, have subsequently been classed as Tribes Hill and referred to the Early Ordovician Beekmantown group. This treatment is based principally on rare *Ophileta complanata* ("*Pleurotomaria hunterensis*"). The Theresa-Tribes Hill boundary is obscure, and gives no apparent evidence of significant change in paleogeography or in conditions of deposition.

On the southeastern border of the Adirondacks, the beds classed as Theresa dolomite are 50–150 feet thick. They consist of alternating sandstones and sandy dolomites, transitional with the Potsdam sandstone on which they rest.

The Theresa beds give way above to the less sandy Little Falls dolomite, which is transgressive upon the Potsdam and Theresa so that at Little Falls it rests directly on the pre-Cambrian crystallines. The Little Falls dolomite is 200–500 feet thick from the New York-Vermont border to Little Falls, but wedges out westward, disappearing before reaching the Port Leyden Quadrangle (Fig. 14). In general, the formation is composed of thick-bedded, gray, finely crystalline dolomite. Some parts are cherty, and there are local sandy lenses. Drusy cavities occur in moderate numbers. Some of these have a first lining of anthracite-like material, believed to be an asphaltic derivative. This lining is covered toward the inside of the cavity, by minute crystals of dolomite, and on these in turn there commonly are crystals of quartz and calcite.

Fossils generally are rare in the Little Falls. There are local lenticular reefs of the calcareous algal deposits termed *Cryptozoön*, and some silicified reefs occur near the top of the formation.

More fossiliferous, lower beds of the Little Falls near Saratoga Springs were named Hoyt limestone by Ulrich and Cushing in 1911. These strata contain the distinctive Upper Cambrian *Tellerina hartii* fauna, with several additional, associated trilobites, some snails, and *Lingulepsis acuminata* and other phosphatic brachiopods.

The Hoyt limestone contains three extensive, successive *Cryptozoön* reef-beds, finely exposed at the "Petrified Gardens" at Ritchie Park and elsewhere near Saratoga Springs. Each of the three reefs is dominated by its own particular *Cryptozoön* species.

The reef layers are commonly 2–4 feet in thickness. Each reef appears to repre-

sent the culmination of a stratigraphic succession or cyclothem that begins with 1–5 feet of quartz sandstone having little calcium carbonate, then a few feet of sandy dolomite, then the 2- to 4-foot reef-layer, in places associated at its base with oölitic limestone, then more dolomite that generally is somewhat sandy and in part may be thin-bedded.

Lithologically, the Hoyt formation includes dark, dense to finely crystalline limestone and alternating beds of grayish dolomites, together with sandy dolomites and dolomitic or calcareous sandstones, some quartzose sandstones and, especially near the base, some black oölitic limestone.

MIDDLE AND UPPER CAMBRIAN OF HUDSON RIVER VALLEY

Some fossils of the Upper Cambrian dicellocephalid faunas have been discovered near Newburgh and Poughkeepsie in the limestones mapped as Wappinger terrane (for location of Wappinger outcrops see Fig. 12). Other parts of the Wappinger, however, contain the Lower Cambrian *Olenellus* fauna, and Ordovician fossils likewise have been found. The Wappinger rocks are thus a complex, and only a small part of their estimated 1,000 feet thickness can be Upper Cambrian in age.

In the Taconic plate, overthrust into its present position near Albany, Upper Cambrian sediments are absent by unconformity at all of the known, unfaulted junctions of Cambrian and Ordovician strata. In general, at these places the Lower Ordovician Deepkill and Schaghticoke shales rest on the moderately folded and eroded edges of the Lower Cambrian Schodack. In Stissing Mountain in northern Dutchess County the thin, local Stissing limestone may be Middle Cambrian in age.

MIDDLE AND UPPER CAMBRIAN OF NITTANY VALLEY AND MORRISON AND FRIENDS COVES IN CENTRAL PENNSYLVANIA

Middle and Upper Cambrian deposits, reaching thicknesses of 3,000 –4,000 feet, are exposed along the axial parts of anticlinal Nittany Valley and Morrison and Friends Coves from central to south-central Pennsylvania (Butts, 1936, 1939, 1945). For the most part, the sediments are dolomites and limestones, with subordinate sandstones that occur chiefly in the Gatesburg formation, and some chert. Shale beds are few, though some of the limestones are argillaceous (Fig. 15).

The oldest strata exposed in the three anticlinal valleys are 200 feet of greenish and dark gray, in part purplish shales, containing some interlayers of greenish micaceous sandstone, some of quartz sandstone, and a few of pea-sized quartz-pebble conglomerate. These sediments contain fragments of *Olenellus* and *Bonnia*, that give evidence of Lower Cambrian age. Because of their general stratigraphic position, and their sandy, in part purplish shales, they have tentatively been correlated with the Waynesboro formation of the Chambersburg region. Fossils have not been found in the Waynesboro in its type region, and it is not impossible

that the supposed Waynesboro of Morrison Cove will be proved equivalent to pre-Waynesboro sediments of the Chambersburg region.

The Pleasant Hill formation contains trilobites of the Middle Cambrian *Alokistocare, Olenoides* fauna. Of its 600 feet of strata, the lower 200 feet are composed of thin-bedded, argillaceous and somewhat micaceous limestones. The higher part is thick-bedded, somewhat purer bluish limestone. Many of these layers, however, have variations in composition, so that on weathering they become peculiarly mottled and "worm-eaten" in appearance; the reopened tubes may actually reflect extensive worm burrows of the ancient calcareous sediments.

Above the Middle Cambrian Pleasant Hill limestone, the Upper Cambrian includes the Warrior limestone, Gatesburg dolomite, and Mines dolomite, totalling 2,500–3,000 feet in thickness. The limestones of the 1,200 feet of Warrior limestone vary from fairly pure to argillaceous and micaceous; dolomitic interlayers are numerous; beds of oölitic limestone recur at a good many horizons, and some of these contain trilobite fragments. *Cryptozoön* reefs are fairly common. Some of the reefs form irregular mounds, but they rarely are more than 5 or 6 feet in greatest thickness.

At Williamsburg in the Huntingdon Quadrangle, the Warrior contains two sandy beds that project as prominent, backbone-like ledges from the northern bank of the Juniata River. The upper of these beds is an arenaceous limestone, approximately 10 feet thick and lying 550 feet stratigraphically below the top of the formation. The second, 75 feet lower, is cored by 6 feet of quartzite. Some of the adjacent dolomite and limestone beds are more sparingly arenaceous, and there are approximately 50 feet of sandy dolomite 180–230 feet above the base of the formation. The sand grains of the two prominent ledges are well rounded to somewhat subangular, commonly 0.1 to 1 millimeter in diameter. Non-quartz grains are rare. The sandstones disappear toward the northwest in the Tyrone and Bellefonte quadrangles.

There is a local absence of the Warrior near Grazier Mill in the Tyrone Quadrangle. Butts (1939) was inclined to attribute this to local warping of the floor of deposition rather than to Appalachian faulting, though he did not regard his evidence as being conclusive.

Species of the early Upper Cambrian trilobites *Blountia, Coosella,* and *Kingstonia* have been described from the Warrior, mostly from beds of the middle and upper parts of the formation. The writer has a *Crepicephalus* tail from the beds near Waddle northeast of State College.

Ascending in the stratigraphic succession, the limestones, argillaceous limestones, dolomites, and dolomitic limestones of the Warrior give place to the 1,600 feet of gray dolomites and thin quartzites of the Gatesburg formation. South of Williamsburg in Morrison Cove, the lower 500 feet of the Gatesburg consist almost wholly of medium-textured, crystalline gray dolomite, without quartzite. In higher parts of the formation, there are numerous interbeds of pure quartz sandstone or quartzite, commonly ranging from 1 to 10 feet in thickness and form-

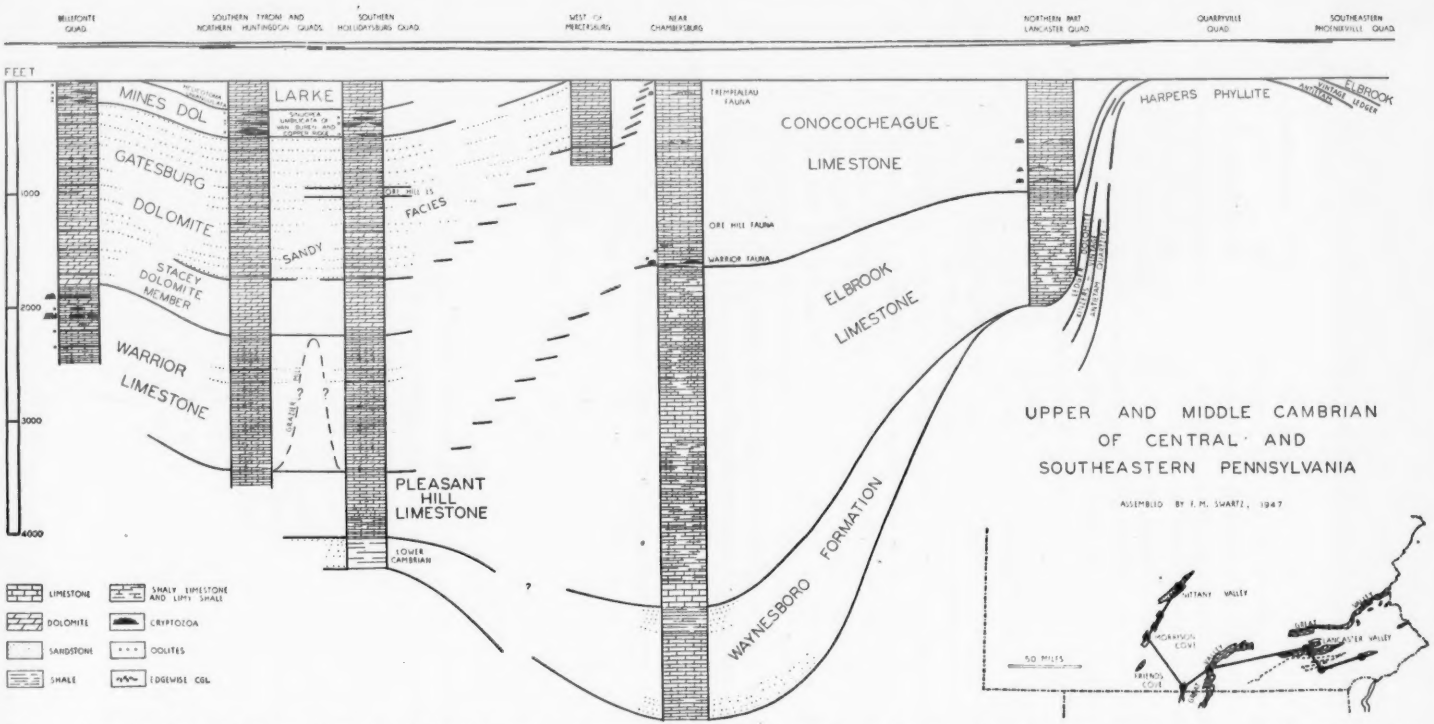


FIG. 15.—Stratigraphy of Middle and Upper Cambrian sediments from central Pennsylvania to south-central and southeastern Pennsylvania. Diagram at top of figure shows over-all thickness changes at true vertical scale. Larke dolomite probably should be included in Lower Ordovician Beekmantown group, and Mines likewise has been so classed by some authors. Waynesboro formation may be Lower Cambrian throughout.

ing 10–15 per cent of the mass. Many of the dolomite layers are dark, medium-textured crystalline; others are thinner-bedded, lighter-colored and finer-textured. Some of the dolomites are oölitic and some are sandy. Pelto (1942) found that near Birmingham in the Tyrone Quadrangle, these facies occur in repeated cycles, in which thin quartzitic sandstones are overlain by thin-bedded to thick-bedded dark dolomite, culminating in some places in *Cryptozoön* layers which are underlain by oölitic dolomite, and generally overlain by buff silty and sandy dolomite.

Approximately 500–600 feet below the summit of the Gatesburg in Morrison and Friends Coves there is a 100-foot body of limestone named the Ore Hill member by Butts. This limestone contains a large suite of trilobites, including *Elvinia roemeri* of the Theresa of New York; *Plethopeltis*, *Saratogia*, and *Pelagiella* of the Hoyt limestone of New York; *Conaspis*, *Elvinia*, *Burnetia*, *Irvingella*, and *Housia* of the Franconia of Wisconsin. James L. Wilson (personal communication, 1947) comments that the *Conaspis* fauna of higher beds of the Ore Hill corresponds with the fauna of the Goodenough member of the Franconia, and that the *Elvinia* fauna occurs in a distinct zone and shows equivalence with the Ironton member of the Franconia. In the lower part of the Ore Hill is a third faunal zone that is duplicated approximately 300 feet above the base of the Conococheague near Chambersburg.

The Ore Hill limestone disappears northeastward in the Tyrone and Bellefonte quadrangle regions of Nittany Valley, apparently by intergradation into dolomite. The quartzitic sandstone interlayers and cyclic character of the Gatesburg persist from Nittany Valley to Friends Cove, with appearance of some calcareous interbeds in the section studied by Wilson in Friends Cove.

At the top of the Gatesburg, quartzite interbeds disappear, and are lacking in the overlying 250 feet of Mines dolomite. The dolomites of the Mines are dark gray and thick-bedded like many of those of the Gatesburg; however, they not only lack the quartzites of the Gatesburg but contain much oölitic chert, which is rare in the Gatesburg formation. Some of the cherts of the Mines are silicified *Cryptozoöns*.

In addition to species of *Cryptozoön*, the Mines has yielded some gastropods, including *Sinuopea* closely similar to *S. umbilicata* of the Copper Ridge dolomite of Alabama. The Mines is correlated by Howell (1944) with the *Saukiella-Cavinella* zone of the Trempealeau of Wisconsin, the higher part of the Conococheague near Chambersburg, and with part of the Copper Ridge dolomite of Alabama.

The Larke dolomite, which overlies the Mines dolomite near Williamsburg in the Huntingdon Quadrangle, consists of approximately 250 feet of thick-bedded, rather coarsely textured, crystalline grayish dolomite with very minor chert and only a few thin sandy interlayers. Butts has identified *Helicotoma uniangulata* in the collections from the Mines. This species was first discovered near Saratoga Springs, New York, in cherts believed to come from the upper part of the Little Falls dolomite. The Larke dolomite is latest Upper Cambrian or earliest Lower Ordovician in age.

MIDDLE AND UPPER CAMBRIAN OF GREAT VALLEY NEAR CHAMBERSBURG AND HAGERSTOWN

Marked changes occur in the Middle and Upper Cambrian strata as they are traced from the anticlinal limestone valleys of central Pennsylvania to the more southeastern Great Valley region near Chambersburg, Pennsylvania, and Hagerstown, Maryland (Stose, 1910; Bassler, 1919; Stose and Bascom, 1929). The sediments thicken; there is increase in volume of argillaceous limestones that grade into calcareous shales; dolomites and sandstones are reduced (middle part of Fig. 15).

The Waynesboro formation, 1,000 feet thick at the bottom of this sequence, has been variously classed as Middle Cambrian and as Lower Cambrian. The latter treatment is probably preferable; the formation has not, however, yielded fossils in the Chambersburg-Hagerstown region, excepting phosphatic brachiopods of *Lingulella* type, and these are of little help in close correlation. The formation seems to be traceable southwestward into the Rome formation of Virginia, which in part at least contains *Olenellus* and definitely is Lower Cambrian in age. Near Chambersburg and Hagerstown, the Waynesboro formation lies above the Tomstown dolomite which contains *Olenellus* and rests on the *Olenellus* beds of the uppermost Antietam.

The Waynesboro formation near Chambersburg and Hagerstown consists of a lower member of gray limestone and calcareous sandstone, a middle member of limestone, and an upper member of purplish to reddish silty shale and argillaceous sandstone. The upper layers are marked by ripple marks and mud cracks.

The Elbrook formation, 3,000 feet thick, consists dominantly of argillaceous limestone and calcareous shale. There are approximately 100 feet of dark blue, thick-bedded, sparingly fossiliferous limestone at the base, overlain by approximately 1,000 feet of minutely laminate shaly limestone and calcareous, greenish and partly purplish shale. At the middle of the formation are some knoll-forming siliceous limestones and thick-bedded dolomites. The upper half of the formation consists of argillaceous limestone and calcareous shale, weathering into fragments which are more blocky than those in the lower shaly member.

The trilobites of the basal limestones of the Elbrook include *Glossopleura bassleri* which is also found in the early Middle Cambrian Rutledge shale of the western side of the Great Valley of southwestern Virginia and northeastern Tennessee. Of higher parts of the Elbrook, much plausibly is Middle Cambrian; but the highest beds may well be Upper Cambrian, possibly corresponding with part of the argillaceous Warrior limestone of central Pennsylvania.

The Conococheague limestone, approximately 1,600 feet thick, forms the bulk of the Upper Cambrian near Chambersburg and Hagerstown. It is composed for the most part of dark blue, banded limestones, containing numerous thin, generally wavy silty laminae that stand in relief on the weathered surfaces. Beds of edgewise limestone conglomerate, in which 2- to 6-inch wide, thin plates of limestone are jumbled together in a limestone matrix, occur at many levels. There

are minor oölitic limestones. Chert is common at some horizons, and some in the lower part of the formation weathers to rough, scoriaceous boulders. Some limestones in the upper 400 feet are purer, pinkish, crystalline and marble-like.

In the lower 250 feet, especially, of the Conococheague there are *Cryptozoön* reef-masses formed by the species, *C. proliferum* and *C. undulatum*, that likewise occur in reefs of the Hoyt limestone in New York. As at other localities, oölitic limestones are associated with the reefs.

On the western side of the Great Valley, west of Chambersburg, the upper 600 feet of the Conococheague contain interbeds of massive sandy dolomites and sandstones, some of them when weathered coherent enough to have been a local source of grindstones.

Bassler (1915) reported the brachiopod *Eoorthis* and dicellocephalid trilobite *Saukia stosei* from the upper beds of the Conococheague, and Resser (1938) termed this the *Tellerina* fauna. James L. Wilson (personal communication, (1947) reports that the fauna of the upper Conococheague is Trempealeau in age, that the lowest of the three trilobite faunas of the Ore Hill member of the Gatesburg of Morrison and Friends Coves occurs approximately 300 feet above the base of the Conococheague near Chambersburg, and that a fauna of Warrior age has been discovered at the base of the Conococheague. These discoveries further document Butts' correlation of the Gatesburg with the greater part of the Conococheague, and show that the Upper Cambrian sandy dolomites of central Pennsylvania interfinger with and grade laterally into the silty, somewhat cherty limestones on the southeast.

MIDDLE AND UPPER CAMBRIAN IN SOUTHEASTERN PENNSYLVANIA EAST OF CHAMBERSBURG

The Waynesboro formation is absent everywhere in southeastern Pennsylvania east of the Chambersburg region; but the Elbrook and Conococheague persist without much lithologic change though with some reduction in thickness into the northern part of the Lancaster Quadrangle (Fig. 15), and into the Reading Prong farther northeast.

In the northern part of the Lancaster Quadrangle, the Elbrook limestone is approximately 1,000 feet thick, and consists of thin-bedded argillaceous limestone and whitish to cream-colored marble with sericitic partings. The Conococheague likewise is approximately 1,000 feet in thickness. It consists of the characteristic light blue limestone with silty laminae, together with some fine-textured whitish marbles and some dolomite. *Cryptozoön* reef beds are fairly common.

Near Reading, Willard and Frazer (1939) report 1,000 feet of Elbrook limestone, consisting of massive bluish gray magnesian limestone with chert bands, and 1,000–1,500 feet of Conococheague limestone, composed of bluish gray limestone with silty or sandy laminae. *Cryptozoön* beds occur in the Conococheague. In Lehigh County, Miller (1941) included the Conococheague and possibly some Elbrook beds in the Allentown limestone.

In contrast to the general eastward and northeastward persistence of the Elbrook and Conococheague from Chambersburg to the northern part of the Lancaster Quadrangle and to the Reading Prong, there is abrupt disappearance of these formations southward from Lancaster to the Mine Ridge region of the Quarryville Quadrangle (Figs. 5, 15). In the valleys flanking Mine Ridge not only the Elbrook and Conococheague disappear, but also the Lower Cambrian Vintage, Kinzers, and Ledger. There has been some question whether part of the Upper Cambrian formations may be represented in the basal part of the Conestoga limestone of Chester Valley (compare Fig. 19); however, the Conestoga is relatively thin, and in part at least is Beekmantown in age according to fossil discoveries. Furthermore, the Vintage, Kinzers, Ledger, and Elbrook reappear beneath the Conestoga farther east in Chester Valley (Figs. 5, 15). Hence, it is reasonably certain that in the vicinity of Mine Ridge and the western part of Chester Valley, the late Lower Cambrian, Middle Cambrian, and most or all of the Upper Cambrian disappear by unconformity beneath the Conestoga. It is not now clear, however, whether this resulted from non-deposition, or from deposition followed by pre-Conestoga uplift and erosion.

POSSIBLE MIDDLE AND UPPER CAMBRIAN OF GLENARM REGION

If the Glenarm rocks of the region south of Chester Valley (Figs. 5, 6) are Cambro-Ordovician in age, it may be that some later Cambrian sediments occur in that region. If so, they presumably would form part of the Cockeysville marble. It is probable, however, that the Cockeysville corresponds with the Conestoga of Chester Valley, and that it is for the most part Beekmantown in age.

REGIONAL RELATIONS, SEDIMENTATION, AND PALEOGEOGRAPHY OF MIDDLE AND UPPER CAMBRIAN DEPOSITS IN NEW YORK, PENNSYLVANIA, AND MARYLAND

BASIC DATA

The data summarized in the stratigraphic charts of Figures 14 and 15 and discussed on accompanying pages, are reëxpressed in the isopachous map (Fig. 16) to illustrate in preliminary fashion the major changes in thickness of Middle and Upper Cambrian sediments of outcrop regions in New York, Pennsylvania, and Maryland. Significant areas of sand accumulation are shown by stippling.

Conditions of sedimentation suggested by these data are also pictured, though with interpretative geological license, in the paleogeographical diagrams of Figure 17. The regional relations, sedimentation, and paleogeography of the Middle Cambrian and the Upper Cambrian of the region are to be discussed in turn with use of all of these charts and maps.

MIDDLE CAMBRIAN

During Middle Cambrian time, the depositional areas of the Appalachian trough were less extensive than in the Lower Cambrian (Fig. 17A). Neighboring

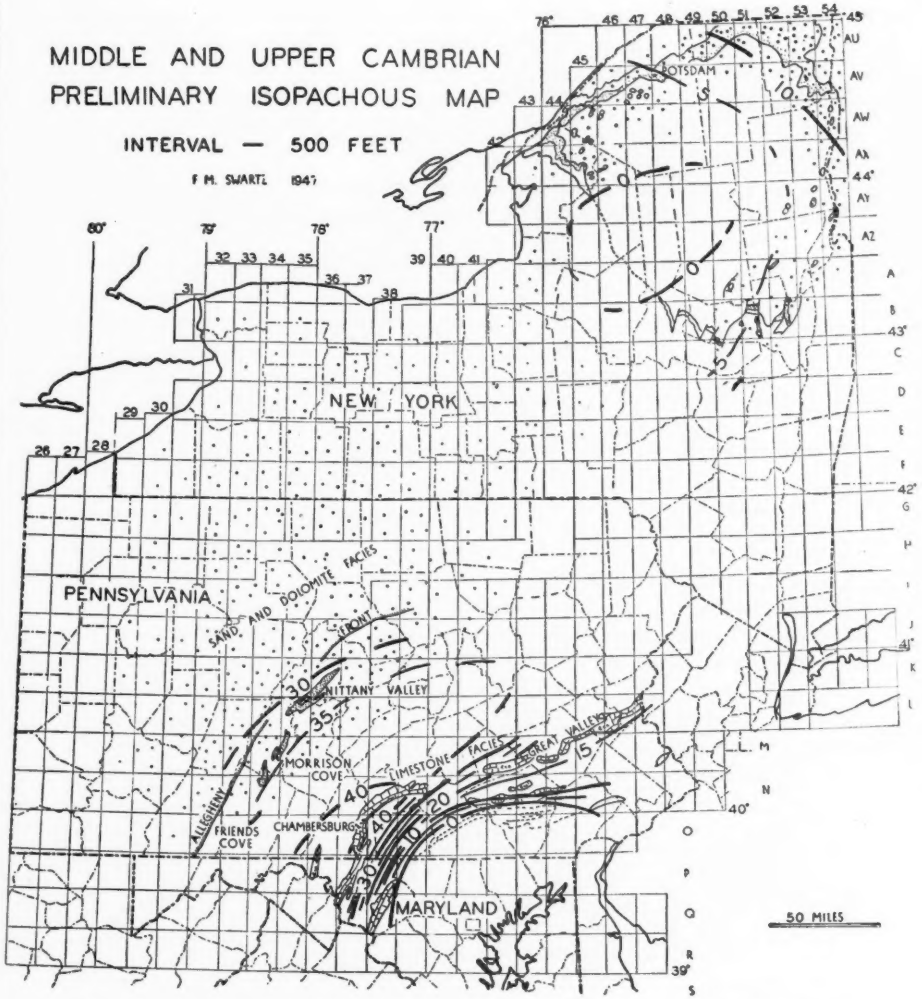


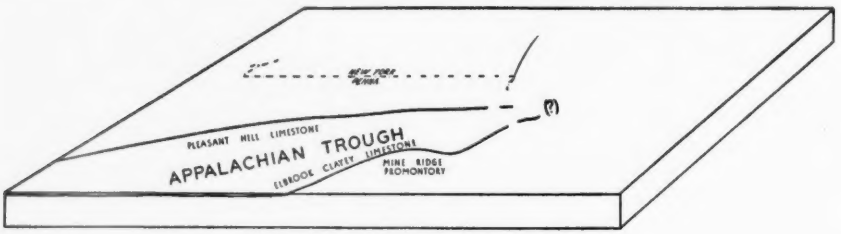
FIG. 16.—Preliminary isopachous map for combined Middle and Upper Cambrian sediments of New York, Pennsylvania, and Maryland. Significant sand accumulations shown by stippling. For location of Wappinger terrane outcrops, see Figure 12.

lands, furthermore, had been lowered and supplied no counterpart of the great volume of Lower Cambrian sand and clay sediments.

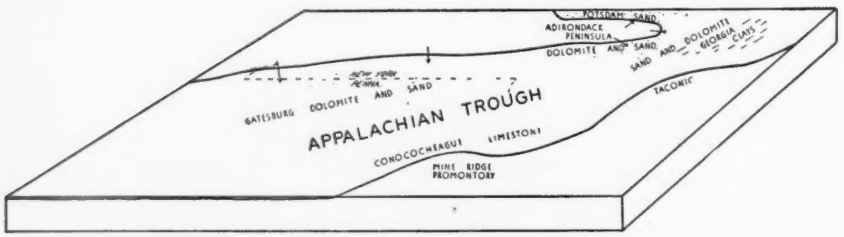
As in the Lower Cambrian, sediments of Middle Cambrian age are lacking along the flanks of the Adirondack Mountains, unless some of the earlier parts of the thick Potsdam sands of the northeastern Adirondack margin may have accumulated at this time.

East of the Adirondacks, in Vermont beyond the New York border, Middle Cambrian deposits are thin and very limited in extent. Middle Cambrian sediments have not been identified in the autochthonous rocks of the Hudson River Valley of New York. The Vermont and southeastern New York regions that were extensively flooded during lower Cambrian time, seem to have been emergent during much of the Middle Cambrian.

The Elbrook deposits, stretching from the Reading Prong region of eastern Pennsylvania to Lancaster and then to the Chambersburg-Hagerstown region



A. PLAUSIBLE PALEOGEOGRAPHY OF MIDDLE CAMBRIAN SEDIMENTATION



B. PLAUSIBLE PALEOGEOGRAPHY OF UPPER CAMBRIAN SEDIMENTATION.

FIG. 17.—Plausible paleogeography of Middle Cambrian and Upper Cambrian sedimentation in New York, Pennsylvania, and Maryland.

of south-central Pennsylvania and central Maryland, form the main known relic of the Middle Cambrian seas that crossed these states. More northwesterly reaches of the sea are represented by the Pleasant Hill limestone of Morrison Cove.

Both the Elbrook and Pleasant Hill plausibly were deposited in extensive, shallow seas, though fossil shells are uncommon. The Pleasant Hill limestone on the northwest is fairly pure, splotched as though by lime-filled burrows of numerous sea-floor worms. On the south and southeast, the Elbrook limestones contain much clay. Geographic relations with the Pleasant Hill suggest that the

source-land of the clay may have been southeast; but detailed correlations and present knowledge of lateral changes are insufficient to establish the direction of transport.

Disappearance of the Elbrook and additional Cambrian sediments below the Conestoga limestone near Mine Ridge in southeastern Pennsylvania gives record of crustal activity in that area during Cambrian time. Either the Mine Ridge promontory shown in Figure 17A was emergent during Elbrook time, or else Elbrook sediments were deposited and then elevated and eroded before the Conestoga sediments began to accumulate.

The sandy, argillaceous, and calcareous sediments of the lower and upper parts of the Waynesboro formation near Chambersburg and Hagerstown indicate a brief increase in erosion of some adjacent emergent area, either at the close of Lower Cambrian or beginning of Middle Cambrian time. Location of the source-land is not established, but may well have been eastward toward the crustally active Mine Ridge and Glenarm regions.

UPPER CAMBRIAN

In Upper Cambrian time, the Appalachian seas spread progressively beyond their earlier confines, and deposited thick sediments in the New York, Pennsylvania, and Maryland region (Figs. 14, 15, 17). Sands accumulated along the northern, eastern, and southeastern margins of an Adirondack peninsula that may have become an island but at least did not wholly submerge during even the farthest encroachment of the Cambrian seas. In Pennsylvania and western New York, quartz sands filtered from the northwest into the northwestern part of the Appalachian trough, and here the thick associated carbonates are mostly dolomites. Along the southeastern section of the trough, the dolomitic and sandy sediments give place to limestones containing thin laminae of silt and moderate amounts of chert.

Throughout the region of deposition, waters seemingly were shallow, and excepting near the Adirondacks were spread upon a nearly flat surface of sedimentary accumulation. In the Hoyt limestone of New York and Gatesburg dolomite of Pennsylvania, slight fluctuations in sea depth produced recurrent, cyclic deposits in the order: sand—dolomite—*Cryptozoön* reef—dolomite. These cycles plausibly reflect repeated gentle subsidence, followed by sedimentary upbuilding possibly with some uplift. Distances of transport of sand into the basin during deposition of the thin sand interlayers, and paucity of associated clays are both notable.

In the Conococheague deposits of the limestone belt, *Cryptozoön* reef beds are relatively common. Oölitic limestones are in part associated with the reefs. Recurrent, edgewise limestone conglomerates reflect shallowing of the water and brief emergences of tidal flats.

Along the northern, eastern, and southeastern flanks of the Adirondack region, initial red-stained feldspathic sands and conglomerates, plausibly of alluvial-lagoonal facies, were succeeded by well washed, ripple-marked quartz sands of

littoral type. Though the reddish feldspathic sands everywhere underlie the quartzose sands, the two facies actually may interfinger. If the change to beach conditions was progressive through the region, parts of the alluvial-lagoonal reddish sands may be equivalent to parts of the quartzose sands winnowed by surf and shore currents. Some local feldspathic conglomerates may represent rapidly accumulated shingle bordering wave-cut bluffs.

The Potsdam sands of the Adirondack margins accumulated upon the submerging surface of the pre-Cambrian complex. The surface was one of low relief, with hills and ridges rising 100 to possibly 200 feet above the floors of near-by valleys. Chadwick has reported residual soil in some places at the Potsdam, pre-Cambrian contact.

Much of the Potsdam sand of the Adirondack flanks seems to have been derived from the Adirondack peninsula. On the eastern Adirondack margin, lateral changes in Upper Cambrian sandy dolomites of Vermont suggest that the sand came from the Adirondacks.

The sandstone interbeds of the Gatesburg of central Pennsylvania are widespread, and extend far south along the anticlinal valleys. Their distribution suggests derivation from land surfaces north and northwest, and not from the moderate-sized Adirondack promontory on the northeast. The Gatesburg, like the Potsdam, received little clay from its source lands. Cambrian soil surfaces lacked the protective vegetative coverings of later geologic ages, and presumably were more subject to wind deflation. Wind transport of fine rock débris in one direction, at times of water transport of sand along other paths, may have helped produce sedimentary distributions peculiar for our modern world. Evidence is not available for evaluation of this factor in preliminary sorting of the Gatesburg sands.

In southeastern Pennsylvania, the Mine Ridge promontory of Figure 17B is suggested by the disappearance of the Upper Cambrian in that region, by unconformity beneath the Conestoga limestone. The emergent surface may have been an updomed island rather than a land-connected promontory Most of the Glenarm region may likewise have been land.

Lower Ordovician

Outcrop areas of Lower Ordovician Beekmantown sediments in New York, Pennsylvania, and Maryland

The "Calciferous sandrock," described by the earlier New York geologists in the limestone regions of the Champlain and Mohawk valleys, has mostly proved to belong to the Lower Ordovician Beekmantown group as named by Clarke and Schuchert in 1899. The name Beekmantown is derived from a town in the northeastern corner of New York, northeast of the Adirondacks.

The belts of outcrop of Beekmantown sediments in New York, Pennsylvania, and Maryland are as follows.

1. Eastern and northern margins of Adirondacks
2. Southern margin of Adirondacks

3. Hudson River Valley
4. Anticlinal limestone valleys of central Pennsylvania
5. Great Valley region near Chambersburg, Pennsylvania, and Hagerstown, Maryland
6. Great Valley, and Lancaster and Chester valleys in Pennsylvania east of Chambersburg region
7. Glenarm region

The Beekmantown sediments of each of these belts are discussed in turn, and the regional relations, sedimentation, and paleogeography are considered.

BEEKMANTOWN OF EASTERN AND NORTHERN MARGINS OF ADIRONDACKS

Lower Ordovician Beekmantown sediments occur in large thickness along the eastern margin of the Adirondacks, from the vicinity of Beekmantown in the northeastern corner of New York, to Shoreham in Vermont (Fig. 18). The latter locality affords excellent exposures that were described by Brainerd and Seely (1890), and furnishes the basis for division of the Beekmantown group now employed in the Lake Champlain region.

In their original description of the Shoreham section, Brainerd and Seely recognized five main subdivisions of the "Calciferous," and in ascending order designated them A, B, C, D, and E. Division A is now regarded as belonging in the Upper Cambrian, excepting possibly the uppermost few feet. Divisions B to E constitute the Beekmantown of the Shoreham section. Division E was grouped with D_3 and D_4 by Cushing (1905) in the Cassin formation named from Fort Cassin, Vermont, where fossiliferous beds contain the *Eurystomites kellogi*, *Plethospira cassina* fauna. Division B was combined by Rodgers (1937) with a few feet of uppermost A in the Whitehall formation named from Whitehall, New York. Cady (1945), however, has found it preferable to use the divisions established by Brainerd and Seely, and for them uses the names Shelburne, Cutting, Bascom, and Bridport.

The Shoreham section is summarized from Brainerd and Seely's description, with faunal notations from Cady.

	Thickness (Feet)
Lower Ordovician or Canadian	
Beekmantown group	
Bridport dolomite	
(E) Fine-grained magnesian limestone, weathering drab, yellowish, or brown, and some purer limestone. *Bucania tripla*, *Bathyurus glandicephalus*	470
Thickness of Bridport limestone	470
Bascom limestone	
(D_4) Blue limestone and interbedded slaty layers. With D_3, this is zone of *Maclurites affinis*, *M. matutinus*, *Hystricurus conicus*, *Isoteloides whitfieldi*. At Fort Cassin equivalent strata contain *Eurystomites kellogi*, *Plethospira cassina*	100
(D_3) Sandy limestone, thin-bedded	120
(D_2) Drab and brownish, magnesian limestone, some sandstone near middle	75
(D_1) Bluish limestone, some calcareous sandstone. Differential weathering of dolomitic matter irregularly distributed in limestones gives weathered surfaces peculiarly "curdled" appearance. Zonal fossil, *Lecanospira compacta*, occurs in D_1, and possibly also in D_2 and C_4	80
Thickness of Bascom limestone	357

	Thickness (Feet)
Cutting dolomite	
(C_4) Magnesian limestone, some black chert	120
(C_3) Sandstones, commonly calcareous and dolomitic	70
(C_2) Thick-bedded magnesian limestone, weathering drab	100
(C_1) Gray, fine-grained, laminated calcareous sandstone. *Ophileta complanata* reported in Cutting above basal sandstones	60
Thickness of Cutting dolomite	350
Shelburne formation	
(B) Thick-bedded, dove-colored limestone and interbedded gray dolomite, transformed to light-colored marble in Shelburne region. *Orthoceras (?) primigenium*	295
Thickness of Shelburne formation	295
Thickness of Beekmantown group	1,525

The rock divisions recognized in the Beekmantown at Shoreham continue toward Beekmantown, New York, with some reduction in thickness and changes in proportions of the limestone-dolomite-sandstone facies. Further marked thinning occurs westward along the northern margin of the Adirondacks, so that in the Thousand Islands region the Beekmantown is represented on the north by approximately 120 feet of Ogdensburg limestone of late Beekmantown age, and near Theresa by 20–40 feet of supposed Tribes Hill sandy dolomite questionably of early Beekmantown age. South of Theresa, even these questionably identified, early Beekmantown strata are lacking along the western margin of the Adirondacks.

Sands associated with the *Ophileta complanata* fauna of the lower Beekmantown increase westward and decrease eastward. They are especially developed near Beekmantown. Their distribution suggests a source area of erosion centering in the regon of the present Adirondacks. Similar relations are observed in scattered sands of the *Lecanospira compacta* zone. On the other hand, slaty terranes near Oak Hill, Vermont, appear to represent clays brought in from the eastern rather than the western margin of the ancient Champlain part of the Appalachian trough of deposition.

BEEKMANTOWN OF SOUTHERN MARGIN OF ADIRONDACKS

Southwestward from Shoreham, Vermont, the Beekmantown limestones rapidly disappear by unconformity, so that no trace of them is found at Saratoga Springs, New York (Fig. 18).

Farther west, at Tribes Hill in the Mohawk Valley, the Late Cambrian Little Falls dolomite is overlain by 40 feet of sandy limestones containing *Ophileta complanata*, *Eccyliomphalus multiseptarius*, and species of asaphid trilobites, all of which give evidence of early Beekmantown age. The sandy limestone was named Tribes Hill limestone by Ulrich and Cushing (1911).

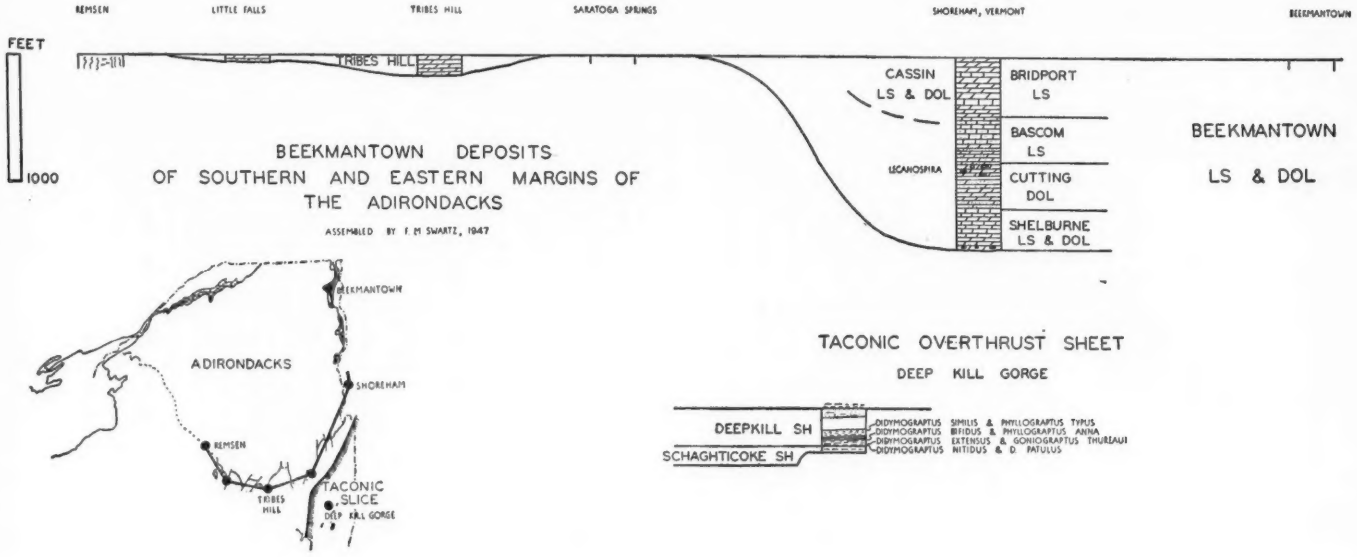


FIG. 18.—Stratigraphy of Lower Ordovician Beekmantown sediments along southern and eastern margins of Adirondacks and in Taconic plate.

West of Tribes Hill, the Tribes Hill limestone thins markedly in a short distance. It wedges out by unconformity between Little Falls and Remsen, and Beekmantown deposits are absent along the western margin of the Adirondacks at least as far north as Theresa.

The Tribes Hill limestone of the Tribes Hill region represents a thin feather edge of Beekmantown deposits lapping from the south onto the margin of the old Adirondack peninsula (Fig. 21).

BEEKMANTOWN DEPOSITS OF HUDSON RIVER VALLEY

Beekmantown deposits occur in the Hudson River Valley of eastern New York both in the allochthone of the Taconic plate, and in the autochthonous Wappinger terrane farther south.

The Wappinger terrane, exposed in small patches near the mid-length of the Hudson River Valley (Fig. 20), consists of approximately 1,000 feet of limestone containing Lower Cambrian, Upper Cambrian, Beekmantown, and Trenton fossil marine faunas. The Beekmantown part of the complex may be 500 feet thick, and may include most of the light gray, fine-textured limestones that constitute the prevailing lithologic facies of the Wappinger rocks. Complex deformation and poor exposures hinder detailed stratigraphic and structural interpretation of the Wappinger strata.

In the Taconic plate, north of Wappinger exposures, the Beekmantown and other deposits have been thrust westward from their more easterly region of original accumulation. The Beekmantown sediments of the overthrust mass or allochthone consist of the Schaghticoke shale and all but the topmost part of the Deepkill shale.

The Schaghticoke shale may be several times as thick as the exposed 50 feet of the type section. It contains the *Dictyonema flabelliforme* and *Staurograptus dichotomus* graptolite faunas, variously regarded as earliest Ordovician or latest Cambrian. The Schaghticoke rests with angular unconformity on the Lower Cambrian Schodack beds.

The Deepkill shales, above the Schaghticoke, are 200–300 feet thick, and consist of thin-bedded shaly limestones, thin-bedded grayish shales, and black clay shales rich in graptolites.

Five graptolite zonal faunas have been discovered in the Deepkill shale, and of these the four Beekmantown faunas are named in Figure 18.

The Schaghticoke and Deepkill were deposited well east of their present location. There has been some suggestion that they represent an easterly trough, distinct from the sedimentary trough in which the Beekmantown deposits at Shoreham were accumulated. It is plausible, however, that they represent clays carried from an easterly area of erosion into the eastern part of the same general trough represented by the sediments at Shoreham. Published data do not give clear evidence of a separated, eastern trough.

BEEKMANTOWN OF NITTANY VALLEY AND MORRISON COVE IN CENTRAL PENNSYLVANIA

The greatest thickness of Beekmantown sediments recognized in the New York-Pennsylvania region occurs in Nittany Valley, central Pennsylvania, near Bellefonte and State College. The sequence here consists of approximately 4,000 feet of carbonate rocks, three-fourths dolomite and one-fourth limestone. There are no significant beds of shale or even of shaly limestone. A single thin and local sandstone member occurs approximately 1,000 feet below the summit of the Beekmantown.

The formations of the Beekmantown of Nittany Valley are as follows (Fig. 19).

	Thickness (Feet)
Beekmantown group	
Bellefonte dolomite	
Medium-bedded, gray, dense dolomite or dolomitic limestone, weathering light-colored, dove gray to whitish. Presumably because of their finely crystalline texture, these dolomites are more closely jointed than are adjacent rocks, and opening of joints on weathered surface produces network of narrow clefts, suggestive of gashes made by sharp knife. Medium-textured grayish dolomite interlayers occur in subordinate quantity at some places. Near middle of formation is local, discontinuous sandstone member, ranging to 30 feet in thickness. Krynine (1940, 1941) reports grains of oölitic chert and heavy minerals, believed to come from erosion of locally upwarped areas of Mines and Gatesburg formations. Thickness of Bellefonte dolomite	1,900–2,100
Axemann limestone	
Medium-bedded, bluish limestone, some layers weathering with brownish, clayey bedding surfaces. Interbeds of dolomitic limestone are rare. Edgewise limestone conglomerates occur at some horizons. *Maclurites affinis*, *Hormotoma artemesia*, and species of *Bathyurus* and *Bolbocephalus* give evidence of equivalence with higher part of upper Beekmantown Bascom limestone of Vermont. Thickness	500
Nittany dolomite	
Thick- to medium-bedded, fairly coarse-textured, crystalline, steely gray dolomite, weathering much darker than Bellefonte formation, and lacking gashed weathered surfaces of that rock. One-inch vugs are common, and occur in well cores at depths of several hundred feet below surface as well as in outcropping ledges. Chert nodules, moderately common, are in part oölitic, the oölites generally smaller than in cherts of Mines formation. *Lecanospira compacta* of lower part of Bascom beds of Vermont Beekmantown, occurs in lower part of Nittany near Bellefonte. Thickness of Nittany dolomite	1,200
Stonehenge limestone	
Medium- to thick-bedded, finely crystalline, bluish, fairly pure limestone, with subordinate interbeds of dolomitic limestone; thin clayey films occur on some bedding surfaces. Edgewise limestone conglomerates at many levels. Asaphid trilobite, *Bellefontia collieana* abundant in upper 50–100 feet, with rare *Hystricurus* aff. *conicus*. *Ophileta complanata* at lower levels. Thickness	500– 600
Thickness of Beekmantown group approximately	4,000

Southward from Bellefonte and State College into the Tyrone Quadrangle and near Williamsburg at the northern entrance to Morrison Cove, the Beekmantown reportedly thins to 3,500 and to less than 3,000 feet. The Bellefonte and

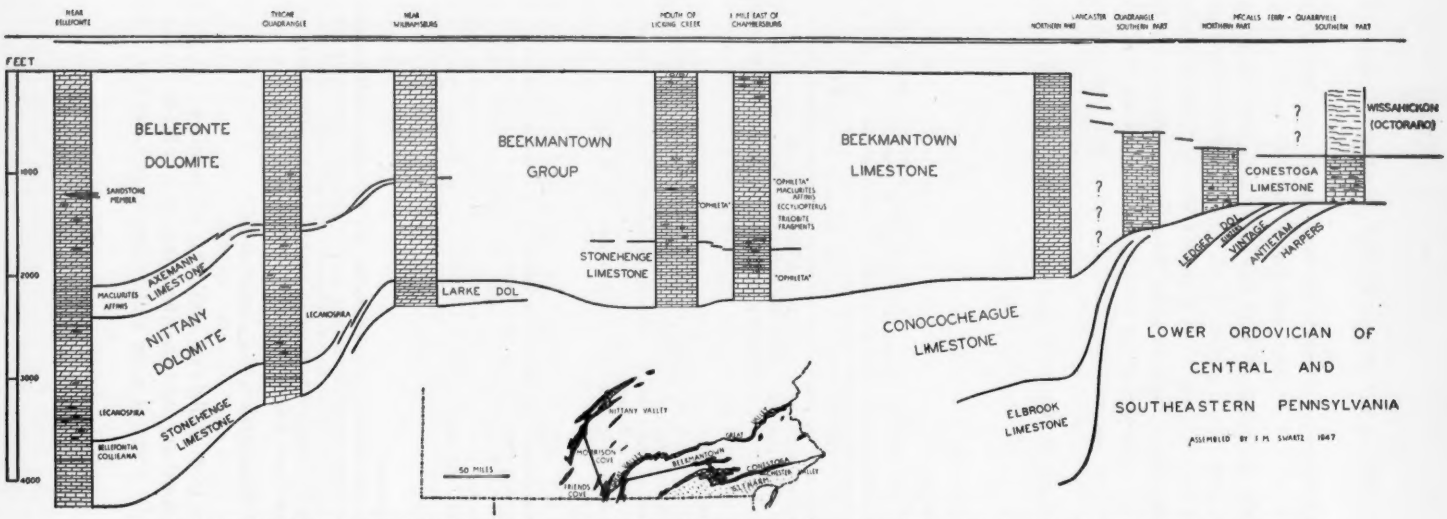


FIG. 19.—Stratigraphy of Lower Ordovician Beekmantown sediments from central Pennsylvania to south-central and southeastern Pennsylvania. True scale of convergence is shown by diagram at top of figure.

Nittany dolomites are persistent, but the Axeman and Stonehenge limestones thin, become irregular, and disappear. Much of the thinning of the limestone formations may result from lateral intergradation into dolomites of the Bellefonte and Nittany facies (Fig. 19).

The Nittany dolomite at Williamsburg, where the Stonehenge formation is missing at least as a limestone, is underlain by 250 feet of thick-bedded, rather coarsely textured Larke dolomite. Specimens of *Helicotoma uniangulata* have been identified by Butts among the rare Larke fossils. Although the original example of the gastropod is believed to have come from the Little Falls dolomite, Butts (1945) is inclined to consider it as evidence of Beekmantown age in terms of usages in the southern Appalachians and Missouri. The Larke in any event is latest Cambrian or earliest Ordovician in age.

BEEKMANTOWN OF GREAT VALLEY NEAR CHAMBERSBURG

In the Great Valley region near Chambersburg, Pennsylvania, and Hagerstown, Maryland, the Beekmantown deposits are approximately 2,400 feet thick, and consist of limestones and dolomites to virtual exclusion of other rock types.

Significant east-west changes occur in the Beekmantown within the Great Valley in the Chambersburg region. In the western part of the Valley, as near the mouth of Licking Creek (Fig. 19), the Beekmantown consists of about half magnesian limestone and dolomite, half purer limestone. The basal Stonehenge limestone member is an ill defined body of fairly pure limestone approximately 700 feet thick that contains little of the dolomitic limestone; in its upper part there are a few silty laminae and some dark limestone conglomerate with red limestone pebbles. There is a thin bed of coarse sandstone about 1,200 feet above the base of the Beekmantown, associated with scoriaceous black chert; some rosette-type cherts occur in the uppermost beds. In the eastern part of the Valley at Chambersburg, the dolomites and dolomitic limestones are reduced in volume, and form about a fourth instead of a half of the Beekmantown mass. The Stonehenge member at the base of the Beekmantown is here approximately 530 feet thick, with numerous silty laminae and thick beds of edgewise limestone conglomerate in its upper half.

The generalized section given by Bassler (1919) for the Beekmantown of the Chambersburg-Hagerstown region can be summarized as follows.

	Thickness (Feet)
Beekmantown limestone	
Fine-grained gray, finely laminated, interbedded limestone and magnesian limestone; in upper part there are some dense whitish cherts, quartzose cherts, and dolomite and limestone conglomerates	440
Turritoma acrea zone. Thin-bedded argillaceous and thick-bedded purer limestones. Many beds weather as though riddled by worm borings	200
Interbedded, dove gray limestone and gray laminated dolomitic limestone, with some limestone conglomerate; some sandy fossiliferous chert 75 feet above base	375
Ceratopea keithi zone, with *Hormotoma artemesia, Maclurites sordidus.* Blue and dove limestone; upper half cherty; at base is blue limestone with rounded quartz grains	250
Cryptozoön steeli, Maclurites affinis, Lecanospira compacta zone. Fine-textured limestone, with a few dolomitic beds. Lower 60 feet oölitic, somewhat cherty	550–650

	Thickness (Feet)
Stonehenge limestone member, containing *Ophileta complanata, Ecciliomphalus multiseptarious, Ribeiria nuculitiformis*. Upper limestones toward east have silty laminae, and beds of oölitic limestone and edgewise limestone conglomerate. Lower limestones are purer, weather whitish, and in part composed of finely brecciated limestone, the limestone fragments commonly less than 2 mm. in diameter	500–700
Thickness of Beekmantown limestone	2,400

The *Maclurites affinis, Lecanospira compacta*, and *Ophileta complanata* faunas are especially valuable for correlations with the Beekmantown of the Champlain region along the border of New York and Vermont.

BEEKMANTOWN IN PENNSYLVANIA EAST OF CHAMBERSBURG

East of Chambersburg, the recognized Beekmantown sediments crop out more or less continuously along the Great Valley into New Jersey, and are exposed in the limestone valleys near Lancaster and in Chester Valley.

Throughout the easterly part of the Great Valley, the Beekmantown rocks consist of limestones and dolomitic limestones that range from 1,000 to 2,000 feet in thickness; excepting that near Harrisburg some poorly preserved graptolites of seeming Beekmantown age occur in shales whose stratigraphy is not well understood.

Near Lancaster, in the northern half of the Lancaster Quadrangle (Fig. 19), the Beekmantown consists of nearly 2,000 feet of gray limestones and interbedded gray laminated dolomitic limestones and dolomites, containing some black chert.

Marked changes occur from the northern to the southern parts of the Lancaster Quadrangle. The 2,000 feet of Beekmantown limestone as known in the northern part of the quadrangle disappear in the southern part, and here instead there occurs the argillaceous Conestoga limestone that persists around the flanks of the Mine Ridge anticline and along Chester Valley with thicknesses of 500–1,000 feet. In the easterly part of Chester Valley, in the Honeybrook and Phoenixville quadrangles, the upper Conestoga consists of thin-bedded, blue to gray granular limestone with thin argillaceous partings; thin dark micaceous phyllites occur in the middle part; in the lower part there are thicker beds of pure granular or marble-like limestone, containing near their base some quartz grains and some limestone conglomerates.

The correlation of the Conestoga limestone is complicated not only by its lack of lithologic similarity with formations a short distance north; but also by the disappearance of the Beekmantown and Conococheague wherever the Conestoga is present, and by the uncertainties about relations of the Wissahickon schists that rest on the Conestoga along Chester Valley. Some poorly preserved fossils found in the Conestoga, however, have been identified with Beekmantown species and it appears to-day that the Conestoga limestone is in general a southeasterly Beekmantown facies, that received clays from a land area southeast of the Appalachian trough.

POSSIBLE BEEKMANTOWN OF GLENARM REGION

For reasons given in the general discussion of the Glenarm problem, it seems probable that the Cockeysville marble near Doe Run, Pennsylvania, is the southerly, somewhat more metamorphosed extension of the Conestoga limestone of adjacent Chester Valley (Fig. 5). In view of the argillaceous character of the Conestoga, and its marked thinning as compared with near-by Beekmantown limestones (Fig. 19), there is furthermore a distinct possibility that appreciable parts of the Wissahickon schists, where they rest on the Conestoga of Chester Valley (Figs. 5, 6), may likewise be equivalent to parts of the Beekmantown limestone.

The hypothesis of lateral change of the Beekmantown limestones, on the northwest, into the originally argillaceous and now phyllitic Conestoga plus some undetermined thickness of Wissahickon schist, is illustrated in Figure 21. This hypothesis of Beekmantown correlation seems reasonably plausible in terms of present knowledge. It carries one step farther the downward "migration" of the clay-limestone boundary that is observed from northwest to southeast in the Ordovician sediments of Pennsylvania, and that results in transformation of Trenton limestones of Nittany Valley into shales near Chambersburg, and possibly in change of the "Stones River" limestones near Chambersburg into Cocalico shale near Lancaster (Fig. 6).

REGIONAL RELATIONS, SEDIMENTATION, AND PALEOGEOGRAPHY OF BEEKMANTOWN DEPOSITS IN NEW YORK, PENNSYLVANIA, AND MARYLAND

Regional features of the Beekmantown sediments of New York, Pennsylvania, and Maryland are illustrated in the stratigraphic charts of Figures 18 and 19. The same data are reassembled and reinterpreted in the preliminary isopachous map of Figure 20, and paleogeographic map of Figure 21.

During Beekmantown sedimentation, seas spread over nearly all of the New York, Pennsylvania, Maryland area, with the principal exception of the Adirondack peninsula (Fig. 21). In the Lake Champlain Valley, and in central and much of southeastern Pennsylvania, flooding was relatively though probably not wholly continuous during Beekmantown time. Along the southern margin of the Adirondacks, however, only lower Beekmantown deposits are represented at the Beekmantown outcrop. The Ogdensburg limestone of the Thousand Islands region represents only later parts of the Beekmantown.

Throughout almost all of their exposures in the three states, the Beekmantown sediments predominantly are carbonate rocks (Figs. 18, 19).

In Pennsylvania, there is an over-all trend toward increase in proportion of dolomite on the west, and increase in limestone in comparison with dolomite toward the southeast. The Beekmantown deposits of Nittany Valley and Morrison Cove in central Pennsylvania include thick dolomite formations that contain almost no limestone interbeds and that compose three-quarters to almost the

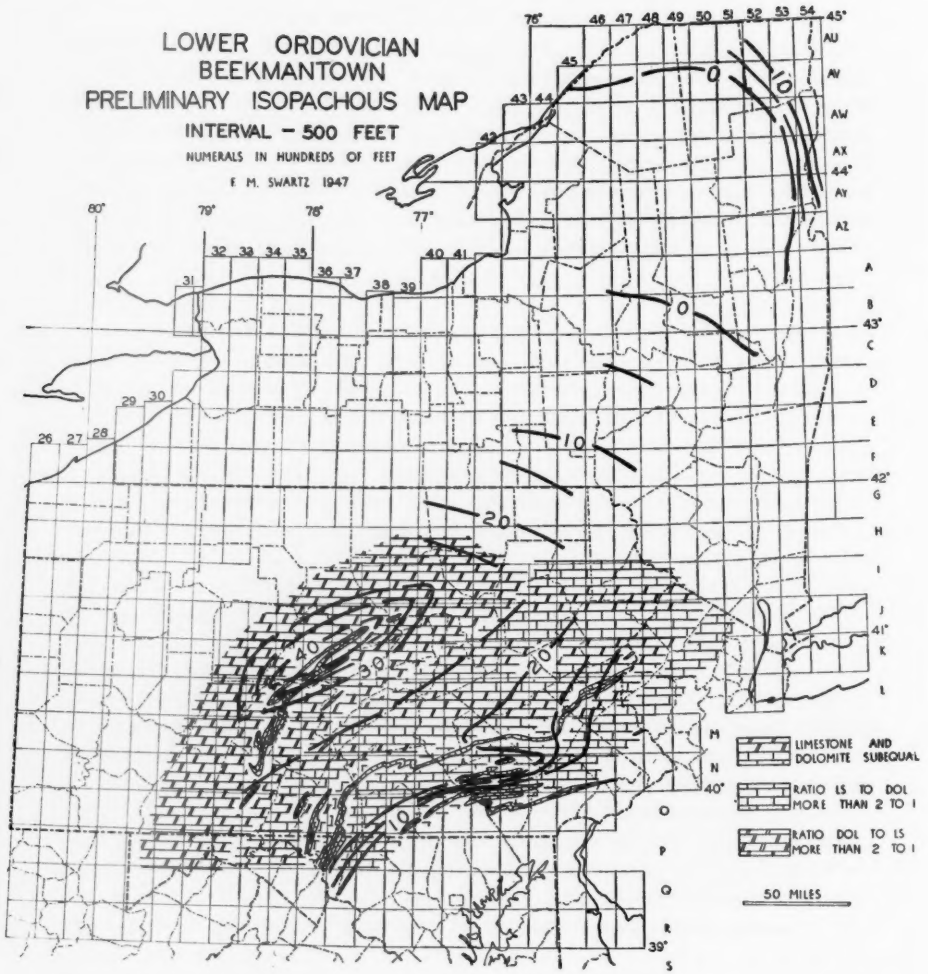

LOWER ORDOVICIAN
BEEKMANTOWN
PRELIMINARY ISOPACHOUS MAP
INTERVAL – 500 FEET
NUMERALS IN HUNDREDS OF FEET
F. M. SWARTZ 1947
LIMESTONE AND DOLOMITE SUBEQUAL
RATIO LS TO DOL MORE THAN 2 TO 1
RATIO DOL TO LS MORE THAN 2 TO 1
50 MILES

FIG. 20.—Preliminary isopachous map of Lower Ordovician Beekmantown sediments in New York, Pennsylvania, and Maryland.

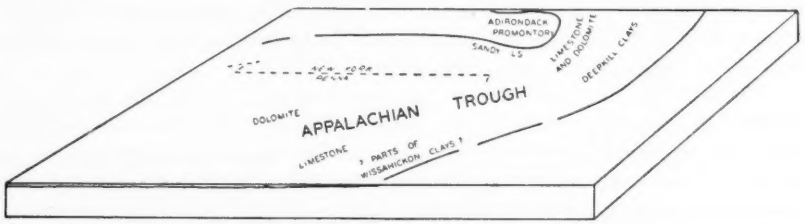
whole of the Beekmantown sequence. In these valleys the subordinate limestone formations thicken northeastward, thin and disappear southwestward. With further information, it may be found that the northeasterly increase of limestone is a component of the general easterly increase.

On the western side of the Great Valley near Chambersburg, south-central Pennsylvania, the Beekmantown sediments consist of interbedded limestones

and dolomites, nearly equal in amount. On the eastern side of the valley, there is appreciable diminution in proportion of dolomite, the dolomitic interbeds forming about a fourth of the Beekmantown succession.

Through the Great Valley regions of eastern Pennsylvania, and in the limestone valleys near Lancaster, the Beekmantown strata consist of limestones and interbedded dolomitic limestones and dolomites, without clearly understood trends. Descriptions of the argillaceous Conestoga limestone of Chester Valley suggest that dolomites are subordinate.

The thin wedge-edge of Tribes Hill lapping onto the southern margin of the Adirondacks includes limestones and some dolomitic limestones. The Beekman-



PLAUSIBLE PALEOGEOGRAPHY OF BEEKMANTOWN SEDIMENTATION. THE DOLOMITE FACIES MAY MARK THE MORE OPEN, SALINE PART OF THE SHALLOW APPALACHIAN SEAWAY. SMALL QUANTITIES OF SAND WERE CARRIED FROM THE LOW-LYING ADIRONDACK PROMONTORY INTO NEIGHBORING WATERS, WHICH RETREATED SOMEWHAT IN LATER BEEKMANTOWN TIME. THIN, GRAPTOLITIC DEEPKILL CLAYS, DERIVED FROM AN EASTERLY LAND SURFACE, ACCUMULATED SLOWLY IN THE ORIGINAL SITE OF THE TACONIC PLATE. PARTS OF THE WISSAHICKON CLAYS MAY LIKEWISE HAVE BEEN DEPOSITED DURING BEEKMANTOWN TIME

FIG. 21.—Plausible paleogeography of Lower Ordovician Beekmantown sedimentation in New York, Pennsylvania, and Maryland.

town sediments of the Champlain region east of the Adirondacks consist of subequal parts of limestones and of dolomitic limestones and dolomites.

Non-carbonate elements form a small percentage of the Beekmantown rock materials of the region. In part these were derived from western erosion surfaces, in part from easterly erosion surfaces; some parts may have come from local uplifts within the general region of flooding; the minor cherts and presumably part of other insoluble constituents of the carbonates were precipitated from solution.

The Tribes Hill limestone of the southern margin of the Adirondacks contains a moderate proportion of quartz sand. There are subordinate sandy dolomites and limestones and some thin sandstones in the Lake Champlain region east of the Adirondacks, but the total amount of sand probably does not constitute more than 5 per cent of the rock mass. One thin sandstone member ranging to 30 or 40 feet in thickness, occurs locally in the upper part of the 4,000 feet of Beekmantown dolomites in Nittany Valley, central Pennsylvania. Limestones, 300–550 feet above the base of the Beekmantown near Chambersburg, Pennsylvania, contain thin silty laminae.

The Beekmantown group is represented in the Taconic plate near Albany, New York, by approximately 500 feet of clayey to silty shales, originally deposited in a more easterly position. In and near Chester Valley in southeastern Pennsylvania, the Conestoga limestone of Beekmantown age contains much argillaceous material. It appears plausible that part of the Wissahickon schist, where it rests on the Conestoga, may represent clays of Beekmantown age (Figs. 7, 21).

The Beekmantown limestones and dolomites generally are not pure enough to be used for chemical purposes. Small percentages of clayey substances may account for part of the impurities, but part should be material deposited from solution.

Cherts occur in parts of the Beekmantown in various regions, but in terms of volume of rock are always very subordinate. Some of the cherts of the Nittany dolomite of central Pennsylvania are oölitic.

The distribution of sands in the Beekmantown sediments of the eastern and southern margins of the Adirondacks strongly indicates that they were derived from the Adirondack peninsula of Beekmantown time. The small volume of sands in the Beekmantown adjacent to the Adirondacks indicates that the Adirondack peninsula was however low and not undergoing rapid erosion. Much of these sands may have been furnished by minor reworking of the Potsdam sediments. The peninsula did not furnish enough clay to give rise to any significant deposits of clay or even of distinctly clayey sands or carbonates.

Grains of oölitic chert in the local sandstone member of the Beekmantown dolomite of Nittany Valley suggest erosion of locally upwarped parts of the Nittany or Mines formations in some reasonably near-by region.

The Beekmantown clays of the Taconic plate near Albany evidently were deposited in the easterly part of the Appalachian trough, and were derived from erosion of an easterly land surface. The clayey materials of the Conestoga limestone of Chester Valley, and the clays of any Beekmantown parts of the Wissahickon, must likewise have come from land surfaces southeast of the trough. The silty laminae of the upper part of the Beekmantown near Chambersburg also came from a source on their east. It is by no means certain, however that these easterly areas of erosion were parts of a single surface of erosion, in the manner illustrated in Figure 21. Instead, the easterly lands of Beekmantown time may have been sufficiently submerged so that there were several large islands. Whatever the exact configuration of the areas of erosion, they were moderate in relief and did not supply a great flood of detritus to the Beekmantown seas.

The silts of the upper part of the Stonehenge near Chambersburg as well as minor sands at higher levels in the Beekmantown, may have been furnished by erosion of a locally elevated part of the sea floor, rather than from the more easterly region that provided the clays of the Conestoga and Wissahickon.

The axis of maximum thickness of known Beekmantown sediments traverses central Pennsylvania and trends northeastward toward the Champlain region

in the manner indicated in Figure 20. The greatest thicknesses of approximately 4,000 feet are found in Nittany Valley. Because of the limited outcrops in comparison with the total area of the three states, only broad features of thickness changes can be pictured in Figure 20.

Shallow-water marine snails, brachiopods, and trilobites are known at many levels in the Beekmantown sediments. Remains of planktonic graptolites occur in dark shales of the Taconic plate, possibly deposited at moderate depths, and a few graptolites have been found in some of the Beekmantown limestones. General rarity of shelly faunas in the dolomitic strata may be due to the dolomitization itself. In southeastern Pennsylvania, recrystallization may cause the lack of known fossils in the Wissahickon. Fossils are rare and poorly preserved in the deformed and partially recrystallized Conestoga limestone. Mechanical fragmentation and solution during sedimentation of course took their toll of shells in all the sediments, especially where wave agitation and currents are more active.

The known Beekmantown sediments of New York, Pennsylvania, and Maryland are for the most part clearly marine. No demonstrably continental or even estuarine deposits have been recognized.

In summary, it appears that during Beekmantown time shallow, marine waters flooded much of the area of New York, Pennsylvania, and Maryland. The northeastward continuation across the Champlain region was constricted by the eastwardly jutting Adirondack peninsula. It is probable that oceanic connections both northeast and southwest helped maintain the marine salinities of the time throughout most of the trough region.

The adjacent land areas were low, and furnished relatively little clastic sediment to the trough. Small quantities of sand were carried from the Adirondack peninsula into adjacent waters. Easterly parts of the Appalachian trough received some clay and silt from lands east of the trough, that may have had the form of an island arc.

General shallowness of water is attested by the beds or lenses of edgewise limestone conglomerates that are fairly numerous in some of the limestone members in central and southern Pennsylvania, by limestone oölites and siliceous oölites where these are present, and by the general characters of the shelly faunas.

In the Pennsylvania region, there is regional increase of dolomites toward the east. The relation of dolomites and limestones to bedding strongly supports the view that dolomitization kept close pace with sedimentation.

Within the regions of sedimentation, gentle and slightly discontinuous subsidence was the over-all tectonic pattern, so that slow downwarping was nearly balanced by sedimentary upbuilding of the surface of deposition. Gentle warping occurred along the margins of the Adirondacks and produced significant fluctuations in borders of the area of deposition. Some erosion of locally upwarped areas within the general region of flooding may have occurred in central and southern Pennsylvania.

Middle Ordovician Chazyan Deposits

Outcrop areas of Chazyan in New York, Pennsylvania, and Maryland

The Middle Ordovician Chazyan limestone was named by Emmons (1842) from Chazy Village near Plattsburg in the northeastern corner of New York state. The distribution of the Chazyan in terms of the outcrop belts in New York differs markedly from that of succeeding parts of the Middle Ordovician, since the Chazyan is wanting along the southern and western margins of the Adirondacks, where Black River and Trenton deposits are extensively developed. Furthermore, the Chazyan is represented by thick limestones along the eastern margin of the Adirondacks, whereas Black River deposits and limestones of Trenton age are thin, and local in development.

The distribution and characters of the Chazyan are discussed under the following headings.

Chazyan of Lake Champlain region in New York and Vermont
Chazyan relations along southern and western flanks of Adirondacks
Chazyan of Hudson River Valley
Chazyan of Nittany Valley and Morrison Cove in central Pennsylvania
Chazyan of Great Valley near Chambersburg
Chazyan in southeastern Pennsylvania east of Chambersburg
Regional relations, sedimentation, and paleogeography of Chazyan deposits in New York, Pennsylvania, and Maryland

Chazyan of Lake Champlain region in New York and Vermont

The Chazyan limestones were named from Chazy Village about 10 miles north of Plattsburg in northeastern New York. Better exposures are, however, found on Valcour Island approximately 5 miles south of Plattsburg, where the Chazyan was divided by Brainerd and Seely (1888; Brainerd, 1891) into parts A, B, and C, given in ascending order. These members were respectively named the Day Point limestone, Crown Point limestone, and Valcour limestone by Cushing (1905). The Valcour Island section can be summarized as follows.

	Thickn es (Feet)
Chazyan group	
Valcour limestone	
Tough arenaceous magnesian limestone, passing to sandstone	17
Dark impure limestone	125
Dove-colored limestone	60
Thickness of Valcour limestone	202
Crown Point limestone	
Bluish black limestone. *Maclurites magna*	75
Dark compact limestone	20
Bluish black limestone, nodular. *Maclurites magna*	210
Gray, thick-bedded limestone, crinoidal	20
Impure nodular limestone. *Maclurites magna*	25
Thickness of Crown Point limestone	350

	Thickness (Feet)
Day Point limestone	
Gray limestone	90
Dark bluish gray limestone. *"Orthis" costalis* (aa)	110
Slaty sandstone grading to slate and nodular limestone	82
Gray or drab sandstone and shale	56
Thickness of Day Point limestone	338
Thickness of Chazyan group	890

The Chazyan sediments near the northern end of Lake Champlain thus consist of approximately 900 feet of limestone, with 140 feet of sandy shale or slate and some limestone at the base, and 17 feet of sandy magnesian limestone at the top. The middle part contains the especially distinctive species, *Maclurites magna*. *"Orthis" costalis* characterizes part of the lower member, and *"Camarotoechia" plena* is found in the upper member. Various early cephalopods occur in each of the divisions of the Chazyan, and brachiopods, gastropods, and trilobites are abundant in some layers.

Chazyan limestones persist southward from Valcour Island through the Lake Champlain region into the marble belt of southern Vermont where they provide some of the marble rocks of the Rutland region. Traced northward, the Day Point member disappears near Shoreham, Vermont, and the sediments undergo various local changes in thickness and facies. In general, the Chazyan sediments dominantly are limestones or marbles through the Lake Champlain region. Some minor sands and clays seem to have been derived from the Adirondack region on the west. Subordinate clastics of sandy and silty limestones of the Valcour limestone near Middlebury, Vermont, appear to have been derived from erosion surfaces east of their area of deposition, possibly from locally upwarped Cambrian sediments.

Southwestward from Shoreham and Rutland, Vermont, the Chazyan sediments disappear beneath the Taconic plate, which obscures their autochthonous characters in the Albany region.

CHAZYAN RELATIONS ALONG SOUTHERN AND WESTERN FLANKS OF ADIRONDACKS

Chazyan sediments are absent throughout the outcrops along the southern and western flanks of the Adirondacks. The thin Pamelia limestone of the Watertown-Lowville region in the Black River Valley west of the Adirondacks has been referred to the Stones River or Chazyan by some geologists, but is classed as Black River by Kay.

The complete absence of Chazyan deposits along the outcrop lines south and west of the Adirondacks suggests that those belts were emergent during Chazyan time, rather than that Chazyan sediments were deposited and then removed by erosion. It thus appears that the margin of the Adirondack emergent surface lay farther south during Chazyan time than had been true during the preceding Beekmantown stage (compare Fig. 20).

CHAZYAN OF THE HUDSON RIVER VALLEY

Chazyan sediments occur in the overthrust masses of the Taconic plate in the middle to northern parts of the Hudson River Valley. It is not now clear to what extent they are represented in the autochthonous Wappinger limestone terrane at mid-length of the Hudson River Valley south of the Taconic plate.

Chazyan sediments are represented in the Taconic plate by the uppermost few feet of the Deepkill shale plus much of the Normanskill shale.

The Normanskill shales are probably 2,000 feet thick. Prevailingly, these shales are dark gray to black. There are some red and green shale horizons, some silty to sandy shales, and some white-weathering cherts.

Two graptolite zones, each with a large and cosmopolitan suite of graptolites, have been recognized in the Normanskill deposits. The lower zone is characterized especially by *Nemagraptus gracilis*, the upper by *Corynoides gracilis*. The *Nemagraptus gracilis* zone has been considered Chazyan by Ruedemann, whereas he has classed the *Corynoides gracilis* beds with the Bla River.

If the structure of the Taconic plate has been prope interpreted by Keith and by Prindle and Knopf (1932), the Normanskill shales and associated sediments of the plate were deposited east of the Chazyan marbles near Rutland, now at the eastern margin of the plate. According to this view, the Normanskill clays were deposited in the eastern part of the Chazyan basin, and came from land surfaces east of the basin.

CHAZYAN OF NITTANY VALLEY AND MORRISON COVE IN CENTRAL PENNSYLVANIA

The Middle Ordovician formations of Nittany Valley and Morrison Cove, central Pennsylvania, described by Charles Butts (1936, 1939, 1945), in his invaluable quadrangle reports, have been reinvestigated by Kay (1944, 1947). Kay's correlations, pending possible modifications after further faunal studies, restrict the Chazyan to the earliest parts of the strata that were so classed by Butts.

In the Bellefonte region (Fig. 23), the Hatter and Benner limestones of Kay, and at some places the Nealmont as well, were included in the Carlim limestone by Butts and referred to the Chazyan. This correlation was based chiefly on large specimens of *Maclurites* that were identified with the Chazyan *M. magna*, whereas Kay believes that they represent other species of the genus.

According to Kay's latest classifications, the Chazyan is represented in the Nittany Valley-Morrison Cove region only by the "Loysburg" limestone, possibly 50–100 feet in thickness. Work on the "Loysburg" has been incidental to Kay's studies of the overlying strata, and neither the stratigraphy of the formation nor its relations to the subjacent Beekmantown are as yet well understood. The strata tentatively classed as Loysburg are impure limestones with some interbeds of dolomite. Some beds have a peculiar lamination leading to the name "tiger-stripe" beds.

At their base, the "Loysburg" strata may be transitional with the Bellefonte dolomite. At their summit, they are believed by Kay to be disconformably overlain by the Hatter limestone of the Black River group.

CHAZYAN OF GREAT VALLEY NEAR CHAMBERSBURG

The Chazyan Stones River limestone, as described by Stose (1909) and Bassler (1919) in the Great Valley region near Chambersburg, Pennsylvania, and Hagerstown, Maryland, is 1,000–1,100 feet thick and consists of interbedded pure and magnesian limestones.

The general succession of these Stones River strata follows.

	Thickness (Feet)
Thick-bedded and some thin-bedded dense to finely crystalline, mostly pure and dove-colored limestones. Small, four-sided, tubular coral, *Tetradium syringoporoides* occurs in some beds	300
Thick-bedded, finely crystalline, dove-colored limestone, with interbeds of dark, medium textured limestones, and finely textured fossiliferous and oölitic limestones, in part having numerous bands of black chert. *Maclurites magnus* fauna, with *Tetradium syringoporoides*, orthid brachiopods, *Bucania*, *Ampyx*, *Eoleperditia*	200
Thick-bedded and thin-bedded, finely crystalline, in part dove-colored and pure limestone, interbedded especially in lower part with dolomitic limestones. Edgewise limestone conglomerates rare	600

The upper beds especially of the Stones River limestone include the purest limestones of the Chambersburg-Hagerstown region, and are extensively quarried.

CHAZYAN IN SOUTHEASTERN PENNSYLVANIA EAST OF CHAMBERSBURG

The Chazyan Stones River limestone extends northeastward from Chambersburg along the Great Valley to and beyond Harrisburg; Cocalico shale of Chazyan or younger age occurs in a small area 30 miles southeast of Harrisburg; if the Glenarm series in southeastern Pennsylvania is Paleozoic in age it may also include Chazyan equivalents originally deposited as clays.

The Stones River of the Great Valley is first described, and possible Chazyan relations farther southeast are briefly considered.

Traced northwestward along the Great Valley in Pennsylvania, the Stones River limestone beds gradually diminish from about 1,100 feet near Chambersburg, to 300 feet where their belt of outcrop crosses the Susquehanna in the southern outskirts of Harrisburg. In part, at least, the thinning is supposed to be due to disappearance of some of the basal part of the formation. As a whole, the Stones River beds persist through this belt as relatively pure, thin- to thick-bedded limestones.

East of Harrisburg, the Stones River is thought to be represented by pure, white sugary marbles and fine-grained blue limestones, that have been opened in numerous quarries along a narrow belt of outcrop between Hummelstown and Lebanon. The easternmost known occurrence of these Stones River strata is at Womelsdorf, 35 miles east-northeast of Harrisburg, where a specimen of *Maclurites* cf. *magna* was discovered in them. No Chazyan sediments have been

recognized farther east in the Great Valley between this place and the Jutland area in New Jersey, 10 miles beyond the Pennsylvania line, where some questionable Chazyan or Normanskill graptolites have been reported in shales of Martinsburg type.

Although there are 300 feet of Stones River limestones in the belt of outcrop extending through Harrisburg, the formation is generally though perhaps not everywhere absent along a parallel synclinal belt extending through Steelton, 2–4 miles farther south (Stose and Jonas, 1939, Fig. 4, p. 81). In the Steelton syncline the Beekmantown is for the most part overlain directly by the Martinsburg shale, or by shaly limestones classed as Leesport and thought to be early Trenton in age. At only a few places have pure limestones of Stones River type been discovered at the junction of the Beekmantown and Leesport strata.

At some localities where the Beekmantown and Martinsburg are in contact along the Steelton syncline, there is good evidence that the boundary is unconformable, and that the Beekmantown underwent emergence and some erosion before the beginning of Martinsburg sedimentation.[5]

The Cocalico shale is known by this name only along a 24-mile belt centering about 30 miles east-southeast of Harrisburg. The formation rests on Beekmantown limestone, and is perhaps 1,000 feet thick, with its summit everywhere truncated by the present level of erosion, so that relations to overlying sediments are not directly established. Poorly preserved graptolites found in 1921 and 1923 were provisionally identified by Ulrich with Normanskill or Chazyan species. Doubt, however, has been thrown on this interpretation of age because the lower part of the Cocalico contains purple and greenish shales and greenish sandstones similar to beds found farther north in basal Martinsburg strata of supposed Trenton age.

The Conestoga limestone farther southeast in the Chester Valley region, was for a time thought probably to be Chazyan in age. The latest fossil discoveries indicate that in part at least it is a Beekmantown equivalent. It is probable that if Chazyan sediments are present in the Chester Valley region they occur within the clayey rocks that have been transformed by metamorphism into Wissahickon schist.

REGIONAL RELATIONS, SEDIMENTATION, AND PALEOGEOGRAPHY OF CHAZYAN DEPOSITS IN NEW YORK, PENNSYLVANIA, AND MARYLAND

In the New York, Pennsylvania region, Chazyan sediments are represented by a more northerly maximum of limestone deposits located along the eastern flank of the Adirondacks in northeastern New York and Vermont; and in the south by another limestone maximum in the Chambersburg-Hagerstown region where the Great Valley crosses the boundary of Pennsylvania and Maryland (Figs. 22, 26). It is possible though not well assured that the limestones of these two main areas of accumulation represent the axial region of a continuous limestone belt that ex-

[5] Graptolites of seeming Chazyan and Beelmantown age are found in some Martinsburg-type shales near Steelton. The occurrences raise stratigraphic-paleogeographic-tectonic questions not satisfactorily answered (Stose, 1946).

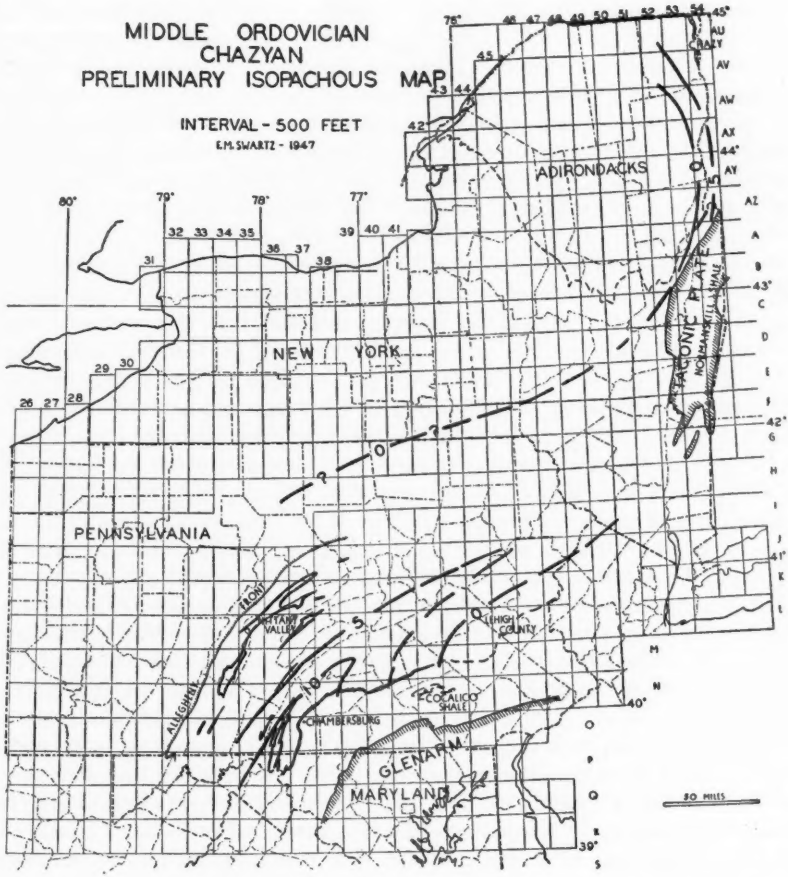


FIG. 22.—Preliminary isopachous map for Middle Ordovician Chazyan sediments in New York, Pennsylvania, and Maryland.

tends southwestward from the type Chazyan area east of the Adirondacks, being covered by the allochthonous Taconic plate in the Hudson Valley region near Albany, New York, and then overlain by thick autochthonous Paleozoic sediments as it extends below ground through the Catskill Mountain region of New York and through the northeastern part of Pennsylvania. Future faunal studies may help both to establish more clearly the degree of equivalence of the limestones of the two areas, and to indicate the ease, or on the other hand difficulty, of intermigration of the creatures of the ancient sea floors.

In both the northern and southern areas, the limestones seem to thin toward the west without known significant development of land-derived clastic sedi-

ments. Especially in the north, clays deposited southeast of the limestone belt give evidence of lands bordering the eastern margins of the basins. So far as evidence is available, the known Chazyan sediments of the region were deposited under marine or brackish rather than fresh-water conditions.

In New York, Chazyan sediments are wanting along the southern and western flanks of the Adirondacks. It is not known that Chazyan deposits occur at depth in New York west of the Adirondack region, although sediments of the age may cross the southeastern part of the state in the manner provisionally suggested in Figures 22, 26.

The Normanskill shales of the Albany region of New York are largely, it is believed, Chazyan in age; but current interpretations suggest that their present location is the result of Taconic overthrusting and that they represent clays originally deposited east of Chazyan marbles quarried in southern Vermont east of the present Normanskill area. Paleogeographically, according to this structural interpretation, lands east of the Chazyan trough were sufficiently elevated to send large volumes of clay and some sand into the eastern reaches of the Chazyan seas.

In the south, the Chazyan Stones River limestones, 1,100 feet thick near Chambersburg, seem to thin out northwestward; at least, the recognized Chazyan or Loysburg limestones of Nittany Valley in central Pennsylvania are only 50–300 feet thick. Eventually, it may be found that some subjacent dolomitic beds are Chazyan in age rather than Beekmantown as is now supposed.

Chazyan sediments are absent in the Great Valley in the Lehigh County region of eastern Pennsylvania. It is not now clear whether this is the result principally of post-Chazyan and pre-Trenton erosion of a Chazyan blanket of sediments, of non-deposition on a promontory projecting from the eastern land areas that bordered the Chazyan trough, or perhaps of non-deposition on a large island-belt that partly separated the trough of limestone deposition, on its northwestern flank, from a southeastern trough partly floored with clayey sediments.

East of Lehigh County, near Jutland in New Jersey, there are shales of possible Normanskill or Chazyan age. Likewise, southwest of Lehigh County, the Cocalico shales may be Chazyan in age, at least in part. If the Glenarm metasediments of southeastern Pennsylvania are Paleozoic in age, they also could include representatives of additional clays and silts deposited during Chazyan time.

Middle Ordovician Black River and Trenton Deposits

Naming of Black River and Trenton, and distribution of outcrops in New York, Pennsylvania, and Maryland

The Middle Ordovician Black River limestone group was named by Vanuxem in 1842 from outcrops along the valley of the Black River on the western flank of the Adirondack Mountains in New York. The "Blue Foetid Limestones and Shales of Trenton Falls" had earlier been described by Conrad in 1837 from the falls of that name on West Canada Creek in the headwater region of the Mohawk Valley, northeast of Utica, New York.

The Black River and Trenton sediments of New York have been studied by many geologists. The earlier stratigraphic versions of Conrad, Vanuxem, Hall, and other workers were reinterpreted during the early decades of the present century by Ruedemann (1901, 1908, 1912, 1925, 1935), whose studies have been especially significant in establishing faunal zones and thus the age and facies relationships of the laterally varying limestone and shale sediments. More recently Kay (1937, 1944) has presented detailed correlations and facies and paleogeographic interpretations of the Black River and Trenton in New York, and has also discussed the equivalent strata in central Pennsylvania.

Major features of the Black River and Trenton sediments in each of the important belts of outcrop in New York, Pennsylvania, and Maryland are summarized under the following headings.

Black River and Trenton of Black River Valley
Black River and Trenton of Mohawk Valley
Black River and Trenton of Hudson Valley
Black River and Trenton of Nittany Valley and Morrison Cove in central Pennsylvania
Black River and Trenton of Great Valley near Chambersburg
Black River and Trenton of Great Valley northeast of Chambersburg
Possible relations of Black River and Trenton southeast of Great Valley
Regional relations, sedimentation, and paleogeography of Black River and Trenton deposits in New York, Pennsylvania, and Maryland

BLACK RIVER AND TRENTON OF BLACK RIVER VALLEY

In the valley of the Black River near Watertown, New York, on the western flank of the Adirondacks, the Black River limestones are 200 feet thick (Fig. 23), and for some distance south rest directly on the crystalline rocks of the Adirondack pre-Cambrian complex. The lower, somewhat impure Pamelia limestone is overlain by 50–60 feet of dove-colored Lowville limestone, long called "Birdseye limestone" because weathered surfaces are spotted by cross sections of the small, calcite-filled worm tubes, *Phytopsis tubulosum*. The small, four-sided prisms of the coral, *Tetradium cellulosum* are locally profuse, and intercalated oölitic and some shaly layers contain orthocerids, trilobites, and *Eoleperditia*. At the top of the Black River group are thin, cherty Leray limestone and Watertown limestone, combined as Chaumont limestone by Kay. The Watertown is characterized by *Gonioceras anceps* and other nautiloids.

Above the Black River strata near Watertown there are in turn another 300–350 feet of more argillaceous and less resistant limestones of the Trenton group, and with these Kay has grouped an overlying 150 feet of shales that are black below, gray and silty above.

The Sherman Fall beds, forming the median 200 feet of the Trenton limestones are more shaly than the lower Trenton limestones; above them likewise are heavier-bedded limestones, overlain by 25–50 feet of shaly limestone transitional with the overlying shale sequence.

A half-inch, discontinuous layer of altered volcanic ash or metabentonite occurs in the lower Trenton Rockland beds of the Watertown area.

Some bedding surfaces of the Trenton limestones bear large-scale ripple-marks with wave-lengths of 2–3 feet. The ridges generally anastamose. They may

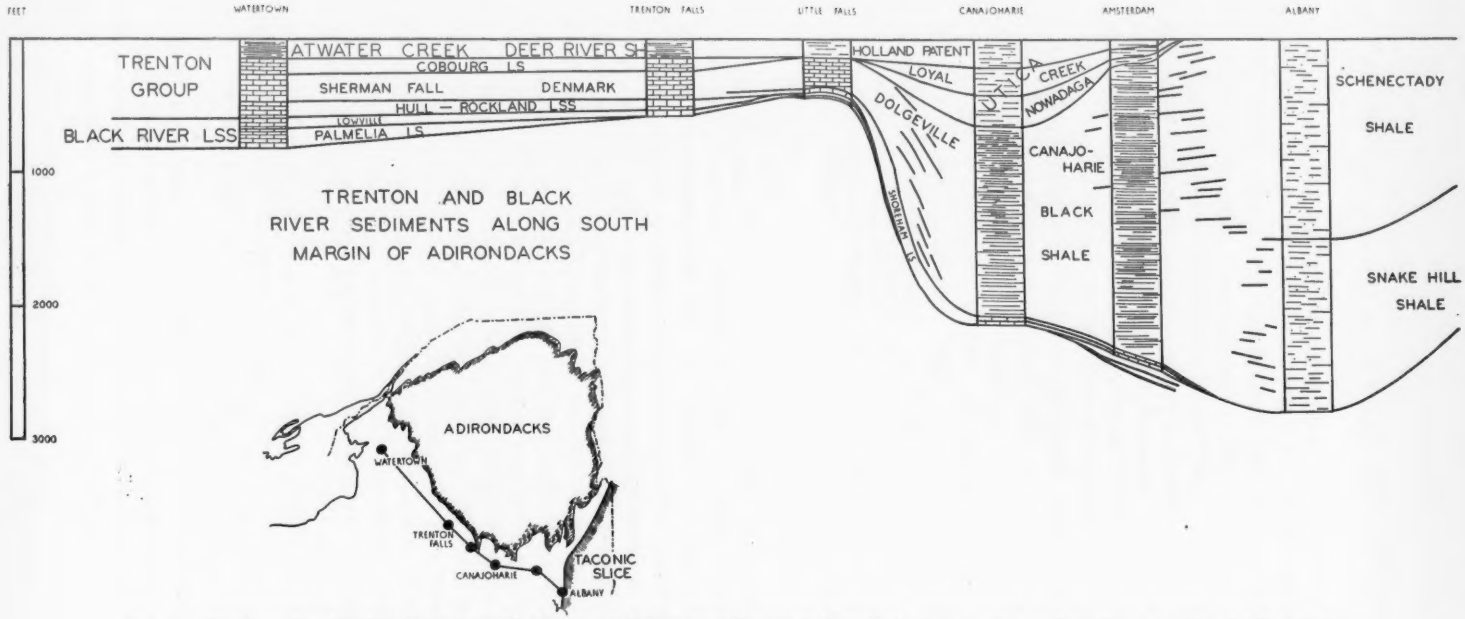


FIG. 23.—Stratigraphy of Middle Ordovician Black River and Trenton sediments in New York along western and southern margins of Adirondacks. (Modified from Kay)

have resulted from storm waves affecting the bottom sediments in fairly shallow but open stretches of the sea; their trends in direction suggest that the storm winds prevailingly came either from the northeast or southwest.

The Trenton strata contain a succession of zonal faunas. In the lowest Trenton Rockland beds are found the gastropods, *Maclurites logani* and *Phragmolites compressus*, together with *Triplecia cuspidata* and other brachiopods, and some significant trilobites and cephalopods. The trilobites, *Encrinurus cybeleformis* and *Hemiarges paulianus*, are important in the Hull limestone. The Sherman Fall limestones contain in their lower third the well known Trenton bryozoan, *Prasopora simulatrix* and the distinctive trilobite, *Cryptolithus tesselatus*. The overlying Cobourg limestone is characterized by the brachiopod, *Rafinesquina deltoidea*. The Deer River and Atwater Creek shales, included at the summit of the Trenton by Kay, are characterized by several of the graptolite zones established by Ruedemann, as well as by the trilobites *Triarthus eatoni* and *Ogygites latimarginatus*.

The sediments are shallow-water, marine deposits, formed in waters generally abounding in marine life. The Trenton limestones especially are characterized by petroliferous odors.

BLACK RIVER AND TRENTON OF MOHAWK VALLEY

The Black River and Trenton strata continue without great change along the southwestern flank of the Adirondacks from Watertown to the vicinity of Trenton Falls in the western part of the Mohawk Valley (Fig. 23). The early Black River Pamelia limestone disappears by unconformity, but the Lowville limestone is persistent. The shaly Sherman Fall limestones are the beds mainly exposed at Trenton Falls. Most geologists working in the Trenton Falls area have drawn the summit of the Trenton at the limestone-shale boundary marking the summit of the Cobourg limestone, rather than within the overlying shales as is done by Kay.

Many of the members of the Black River and Trenton groups of the Watertown-Trenton Falls region are separated by inconspicuous disconformities. Fluctuations of the platform of deposition were sufficient to cause transgressions and regressions of the sea waters, but the emergences were gentle and were not accompanied by pronounced warping or deep erosion.

Marked changes take place in the Black River and Trenton sediments as they are traced from Trenton Falls eastward along the Mohawk Valley (Fig. 23). The sequence thins near Little Falls, with disappearance by disconformity of the Black River and early Trenton, as well as of the later Trenton Cobourg limestone.

East of Little Falls the sediments expand markedly and undergo marked changes in lithologic and faunal characters. Shales and somewhat silty shales supposed to correspond in age with the Cobourg limestone and overlying shales at Trenton Falls and farther northwest, are questionably classed as Utica shale. The Sherman Fall limestones first pass into the very argillaceous Dolgeville lime-

stone and, with further increase in clay and decrease in lime, become the graptolitic Canajoharie black shale of the eastern part of the Mohawk Valley. Continuing eastward, the upper beds of the Canajoharie become silty and grayish as they begin to pass into the Schenectady shale. Only the lowest beds of the Sherman Fall, and locally parts of the early Trenton and Black River, continue as limestones into the eastern part of the Mohawk Valley.

Several thin metabentonites occur in the Canajoharie shale and in the underlying Trenton limestones of the eastern part of the Mohawk Valley.

The Canajoharie shales are largely black, clay shales in the lower half, interbedded black and gray, silty shales above. Ruedemann established five graptolite zones in the Canajoharie, that have been especially valuable in correlation of these strata. He further discovered that the graptolites of both the Canajoharie and Utica are arranged in the sediments so as to reflect the influence of prevailing northeasterly currents.

The increase in abundance of graptolites in the Canajoharie is accompanied by reduction of the bottom-dwelling brachiopods and trilobites profuse in equivalent sediments farther west.

The faunal change presumably is due primarily to the lessened oxygen and increased organic fouling of the bottom waters.

Thinning of the Black River and Trenton deposits near Little Falls gives evidence of a southwest-trending axis of recurrent upwarping termed the Adirondack axis by Kay. The structural conditions of Black River and Trenton times contrast with those of the Late Cambrian and Early Ordovician, since a westward extension of the Adirondack dome is reflected by the absence of sediments of these ages along the western margin of the Adirondacks.

The eastward increase in clay and silt observed in the Trenton sediments of the Mohawk Valley continues in the Hudson Valley. The sediments give evidence of an easterly land area, rising during Trenton time so that first clays and later silty clays and sands were carried farther and farther west.

BLACK RIVER AND TRENTON OF HUDSON VALLEY

Where the Mohawk Valley joins the Hudson Valley near Albany, New York, the upper part of the type Canajoharie shale is replaced by 1,500–2,000 feet of grayish Schenectady shale, containing interlayers of siltstone and fine-grained sandstone (Fig. 23). In varying beds there are graptolitic, brachiopod-trilobite, and cephalopod faunas. Some strata contain numerous eurypterids and may reflect nearer-shore or estuarine-lagoonal, brackish rather than truly marine waters.

The earlier Canajoharie shales found beneath the western part of the Schenectady shale, are replaced in the Albany area 1,000–2,000 feet of grayish, silty and somewhat sandy Snake Hill shales. The Snake Hill shales may have been shifted by the Taconic faults of the Albany region, and it is not certain that they belong beneath the outcropping Schenectady beds in normal stratigraphic succession as

is illustrated in Figure 23. Parts of the Snake Hill shale are graptolitic. Oxygenated, marine bottom waters are represented by other strata that are rich in brachiopods, snails, and trilobites.

The thin Rysedorf conglomerate at the top of the Normanskill shale east and southeast of Albany is definitely one of the deposits of the Taconic plate. It ranges in thickness from one or two feet to 50 feet at a few places. Contained pebbles are fossiliferous, and Ruedemann has discovered in differing pebbles six different faunas ranging in age from Lower Cambrian to Trenton. The faunas are mostly exotic, with groups of species somewhat different from those found in formations of approximately corresponding ages in New York. The pebbles seemingly represent detritus worn from an eastern upfold of strata, which in part were deposited in a trough distinct from New York early Paleozoic basins of sedimentation.

In the Hudson Valley south of the Taconic plate, sediments of Trenton age are represented by the upper part of the Wappinger terrane plus parts of the overlying Ordovician shales. The grayish, silty, and sandy Trenton-age shales both here and near Albany reflect erosion of a more eastern, extensive land surface.

BLACK RIVER AND TRENTON OF NITTANY VALLEY AND MORRISON COVE IN CENTRAL PENNSYLVANIA

The Black River and Trenton sediments of Nittany Valley and Morrison Cove were treated as mappable lithologic units by Charles Butts in his various reports for the Nittany Valley-Morrison Cove region of central Pennsylvania. Thus the top of the Trenton was drawn at the junction of the limestone sequence with the overlying 1,000–1,100 feet of Reedsville shale (Fig. 24). The Trenton limestone was made to include a series of dark, aphanitic, conchoidally fracturing, impure limestones, containing in the upper parts interbeds of finely crystalline gray coquinites and some calcareous shales. The Trenton trilobite, *Cryptolithus tesselatus*, ranges virtually throughout the sequence. *Brongniartella* (*Homalonotus*) *trentonensis* occurs persistently in the lower fourth of the mass. Species of *Rafinesquina*, *Sericeus*, *Dalmanella*, *Calymene*, *Isotelus*, and *Ceraurus* are common to abundant in the higher coquinites.

The dark, aphanitic, sparingly fossiliferous beds of the lower part of the Trenton as mapped by Butts differ markedly in lithology from the underlying, generally bluish gray limestones that he referred to the Black River and Chazyan groups.

The Black River and Trenton sediments of central Pennsylvania have been reinvestigated by Kay (1944), with important additions to knowledge of the stratigraphic relations and diastrophic history of the sediments.

Lower, dark shales of the Reedsville formation, containing *Triarthus eatoni*, have been named Antes Gap shale by Kay and are referred by him to the Trenton group (Fig. 24).

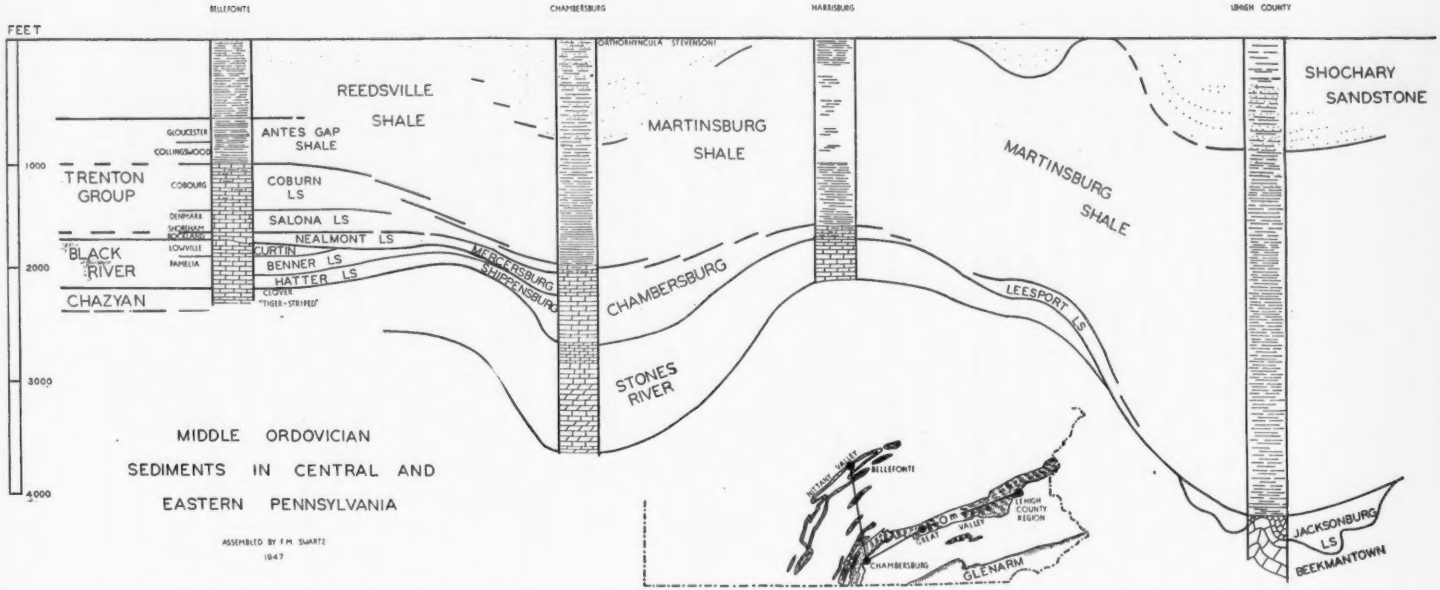


FIG. 24.—Stratigraphy of Middle Ordovician Black River and Trenton sediments from central Pennsylvania to south-central and eastern Pennsylvania.

The Nealmont limestone, included at the base of the Trenton by Kay, is finely crystalline, somewhat argillaceous, and weathers bluish gray. It lacks *Cryptolithus tesselatus* of the overlying limestones, and is characterized especially by *Maclurites* cf. *logani*, whose close relatives are distinctive of the older Chazyan and Beekmantown deposits.

The base of the Nealmont is a disconformity having significant regional effects. However, where the high-calcium Valentine limestone of the next older Curtin beds is missing, the base of the Nealmont is commonly obscure. In general, the lithologic and faunal change at the top of the Nealmont tends to be better marked than that at its base.

The Black River limestones as understood by Kay in Nittany Valley are 400–500 feet thick. They consist for the most part of limestones that weather bluish gray. Some beds are moderately argillaceous and some contain small amounts of silt. The silty residues left after solution are not entirely clastic, but in some layers include minute, doubly terminated quartz crystals and some authigenic feldspars.

The upper or Valentine member of the Curtin division of the Black River group ranges from 40 to 90 feet thick in the Bellefonte region in Nittany Valley, and is one of the purest, high-calcium limestones of the Appalachian region. It is used for chemical lime and is worked near Bellefonte in several deep mines. High-grade limestones occur in some other divisions of the Black River in Nittany Valley and Morrison Cove, but are not so pure as the Valentine quarry ledge.

The Valentine limestone is sparingly fossiliferous, but does contain some *Eoleperditia* and some conodonts. Some other parts of the Black River beds contain brachiopods and trilobites, as well as the coral, *Tetradium*, and some other types of marine fossils.

Several 3- to 6-inch layers of metabentonite occur in the Black River and lower Trenton of central Pennsylvania. They have been used for correlation of sections within the Nittany Valley-Morrison Cove area, and also have been traced to the Great Valley region in southern Pennsylvania and Virginia.

BLACK RIVER AND TRENTON OF GREAT VALLEY NEAR CHAMBERSBURG

In the Great Valley region near Chambersburg, Pennsylvania, and Hagerstown, Maryland, the purer limestones of the Chazyan Stones River formation are overlain by 200–700 feet of more argillaceous limestone named Chambersburg limestone by Stose. Above these in turn are the 2,000 feet or more of Martinsburg shale, sandy in its upper part (Fig. 24).

Trenton faunas occur in the basal part of the Martinsburg, and it was early recognized that parts of the Trenton limestone of central Pennsylvania are represented in the Chambersburg region by the clayey sediments of the lower Martinsburg. It is this change in relation of the basal beds that has led to the usage of Martinsburg for the Ordovician shales near Chambersburg, and Reedsville for their thinner tongue in the Nittany Valley region.

Six members were recognized in the Chambersburg in the Hagerstown-Chambersburg region by Stose (1910) and Bassler (1919), including zones characterized by the coral, *Tetradium cellulosum*, the ball-cystid, *Echinosphaerites*, and the questionable alga or sponge, *Nidulites*. Some of the members seem to wedge in and out by disconformity. Some of the changes in the upper part of the Chambersburg, however, may be related to intertonguing of limestones with shaly beds of Martinsburg type.

The bulk of the Chambersburg limestone was correlated by Stose (1910) and Bassler (1919) with the Black River limestone of New York, largely on the basis of faunal identifications by Ulrich. The basal zone of the Chambersburg was considered possibly to be latest Chazyan, and the topmost zone was thought to be Black River or earliest Trenton.

Recent work by Kay and his associates suggests division of the Chambersburg into Shippensburg limestone, below, and Mercersburg, above. The Shippensburg is thought to be equivalent to the earliest Black River of central Pennsylvania (Fig. 24). Higher parts of the Black River are absent by a disconformity at the boundary of the Shippensburg and Mercersburg strata. The Mercersburg is classed as early Trenton, equivalent to the Nealmont of central Pennsylvania.

The Martinsburg of the Chambersburg region includes 1,000 feet of lower gray and some black shale, calcareous in the basal 100 feet, and 1,000–1,500 feet of upper greenish shale and much interbedded sandstone. The lower 1,000 feet were provisionally classed by Bassler as "Trenton and (?) Utica;" higher parts were correlated with the Eden and Maysville. Fossils were found in only the lower 100 feet of the "Trenton-Utica" division, and the Trenton-Utica age of the remainder of this division is not yet well established.

BLACK RIVER AND TRENTON IN GREAT VALLEY EAST OF CHAMBERSBURG

The Martinsburg shale crops out continuously along the northern part of the Great Valley from Maryland across southeastern Pennsylvania into New Jersey (Fig. 24). Near Harrisburg, the upper sandy beds of the Chambersburg region disappear by unconformity, plausibly because of upwarping and erosion rather than non-deposition. At the base of the Martinsburg, the Chambersburg limestone of the Chambersburg region thins northeastward. It is 100–150 feet thick at Harrisburg, but is not known east of Harrisburg. It is absent at the base of the Martinsburg along the Steelton syncline several miles south of Harrisburg, at least as recognized Chambersburg limestone.

Part of the northeastern disappearance of the Chambersburg is probably due to a facies change into Martinsburg shale.

East of Harrisburg, and also along part of the Steelton syncline south of Harrisburg, shaly limestones occurring at the base of the Martinsburg have been named Leesport limestone by Stose and Jonas from a town 50 miles northeast of Harrisburg. The Leesport limestone at its type locality is 100 feet thick, is shaly, and in its middle part contains some calcareous quartzose sandstone and some

arenaceous limestone. The Leesport beds are extensively quarried for "cement rock."

Fragmentary fossils have been found in the Leesport, but do not furnish close correlations. The Leesport may be a more shaly equivalent of part of the Chambersburg limestone.

Another early Trenton limestone occurs in Lehigh County, eastern Pennsylvania, and is there known as Jacksonburg limestone. A fairly large fauna has been discovered in the limestone and gives evidence of early Trenton, Hull-Rockland age. The Jacksonburg limestone was warped or gently folded, and was locally removed by erosion before deposition of the Martinsburg clays (Fig. 24).

Throughout the Harrisburg-Lehigh County regions of the Great Valley, as near Chambersburg, the thickness of Trenton equivalents included in the Martinsburg remains uncertain.

Local amygdaloidal basalt flows occur at the base of the Martinsburg shale near Jonestown, 25 miles northeast of Harrisburg. The flows rest on Beekmantown limestone. Stose and Jonas have suggested that hard purple and green shales at the base of the Martinsburg in the Jonestown region may represent layers of fine-textured volcanic ash.

At the close of Martinsburg time, the Martinsburg and older strata were folded in eastern Pennsylvania, and the anticlinal arches were considerably eroded before deposition of the overlying sediments.

POSSIBLE BLACK RIVER AND TRENTON RELATIONS SOUTH OF GREAT VALLEY

Black River and Trenton sediments have not definitely been recognized in southeastern Pennsylvania south of the Great Valley.

The Cocalico shale 30 miles southeast of Harrisburg has furnished a few poor graptolites originally identified tentatively with Normanskill or Chazyan species. Purple and greenish shales near the base of the Cocalico are, however, similar to those near the base of the Martinsburg near Jonestown, and suggest that the Cocalico may be early Martinsburg or Trenton in age.

If the Glenarm rocks of southeastern Pennsylvania consist of metamorphosed Paleozoic sediments, sandy clays of Trenton age may be represented in the Wissahickon and Peters Creek schists.

REGIONAL RELATIONS, SEDIMENTATION, AND PALEOGEOGRAPHY OF BLACK RIVER AND TRENTON DEPOSITS IN NEW YORK, PENNSYLVANIA, AND MARYLAND

During Black River time, the New York, Pennsylvania, Maryland region was a nearly flat platform, which was however depressed below sea-level and flooded by shallow seas along a belt extending from the Watertown-Trenton Falls region of north-central New York to the Nittany Valley and Chambersburg areas of central and south-central Pennsylvania. It is probable that the same seas covered

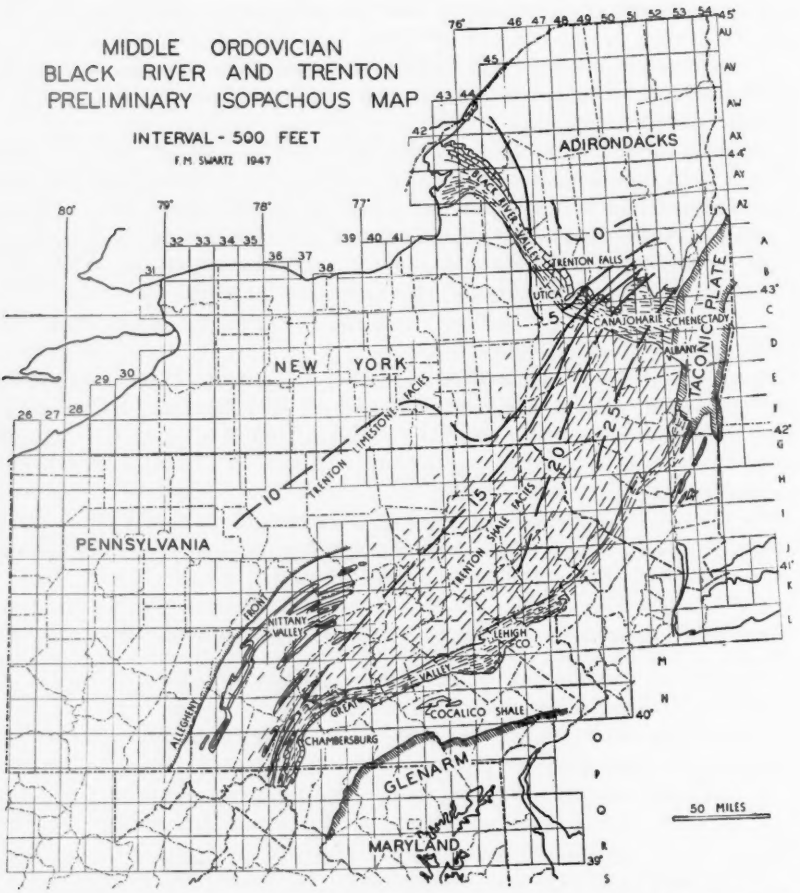


FIG. 25.—Preliminary isopachous map for Middle Ordovician, Black River and Trenton sediments in New York, Pennsylvania, and Maryland. Thickness values used in eastern Pennsylvania are problematical because of uncertainties about proportion of Martinsburg shale that is Trenton in age. True eastern thicknesses may be less than those used in diagram.

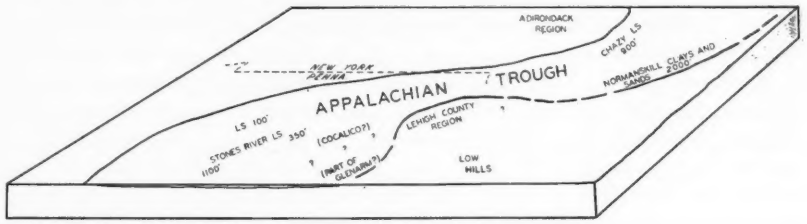
the more western parts of both New York and Pennsylvania during parts of Black River time (Fig. 25).

During Black River time the platform of deposition fluctuated in altitude and underwent gentle, differential warping so that the seas shifted in outline and at times withdrew from large sections of the general region. The central part of the Adirondack region may have stood out of water as a low-surfaced island, and an arch seems to have extended southwestward along Kay's Adirondack

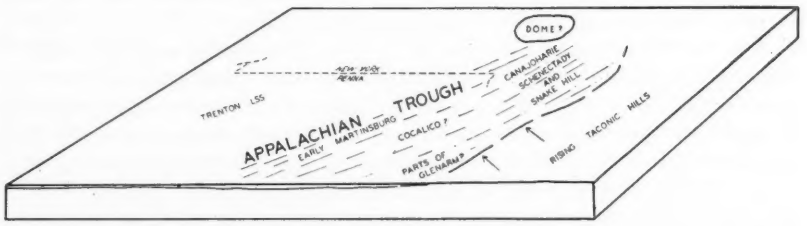
axis. Minor floorings occurred east of this axis along the southeastern and eastern flanks of the Adirondacks.

In southeastern Pennsylvania, deposits of Black River age are not definitely known east of Harrisburg.

Some of the limestones of Black River time are exceptionally pure, and accumulated in basins receiving almost no detritus from surfaces of erosion. Other limestones contain subordinate amounts of clay and a little silt. In some places doubly terminated quartz crystals were formed, perhaps as overgrowths on tiny silt fragments, and some small needles of feldspar crystallized from solution.



PLAUSIBLE PALEOGEOGRAPHY OF CHAZYAN SEDIMENTATION. IT IS NOT CERTAIN WHETHER ANY CHAZYAN SEDIMENTS ARE REPRESENTED IN THE COCALICO AND GLENARM CLASTICS. THE LEHIGH COUNTY REGION MAY HAVE BEEN AN ISLAND RATHER THAN A PROMONTORY.



PLAUSIBLE PALEOGEOGRAPHY OF MIDDLE TRENTON SEDIMENTATION. CLASTICS ERODED FROM THE RISING TACONIC HILLS PASS WESTWARD INTO SHALLOW WATER MARINE LIMESTONES.

FIG. 26.—Plausible paleogeography of Middle Ordovician Chazyan and of Middle Ordovician Trenton sedimentation in New York, Pennsylvania, and Maryland.

Significant clay and sand sediments of Black River age have not been recognized in New York, Pennsylvania, and Maryland. The land sources of the minor clay and silt components of the less pure limestones are not established. In part, such material may have been derived from temporarily emergent parts of the general platform of deposition. In part, they may have been brought in by wind transport rather than by streams.

Chert nodules are not conspicuous in the Black River sediments, except locally as in the late Black River Leray limestone of north-central New York.

A few thin falls of volcanic ash, changed chemically by action of the sea waters in which they fell, are known in Black River sediments in central Pennsylvania,

and one occurs in the Black River near Watertown, New York. Location of the vents from which these ashes were exploded is not well established, but may have been east of the more southern part of the Appalachian trough.

The Black River waters of New York and Pennsylvania were in general marine, and at times supported considerable numbers of corals, brachiopods, and nautiloid cephalopods. Bottom-dwellers, however, were rare in the seas that deposited the highest calcium carbonate sediments, such as the Valentine limestones of central Pennsylvania. Conodonts lived in the Valentine waters, and some *Eoleperditias* were present. Whether presence of these creatures and rarity of the bottom-dwelling brachiopods and trilobites resulted from some special degree of salinity of the waters, from depth, or from some other physico-chemical relationship, is not now clear.

Conditions like those of the Black River age continued into earliest Trenton time, though here limestone-depositing marine waters were more widespread in eastern New York, and also extended into the Jacksonburg limestone area of eastern Pennsylvania. By the beginning of Sherman Fall time, however, lands east of the New York Pennsylvania trough region were affected by the initial stages of the Taconic deformation. As they rose they underwent erosion of increasing vigor and so supplied a flood of clay that spread farther and farther westward onto the platform of sedimentation. Silts and some sands reached areas of Martinsburg sedimentation in Pennsylvania and Snake Hill and Schenectady deposition in eastern New York (Figs. 22, 26).

The western limestones, deposited where bottom waters were well oxygenated, contain numerous brachiopods, bryozoans, and trilobites. Fine clays that accumulated in waters of fair depth, where bottom waters were poorly oxygenated in relation to the fouling action of decomposing organic detritus, generally have few fossils of bottom-dwelling shell life. Some of these contained numerous graptolites excellent for age zonation because of rapidity of their evolution. Farther east, some of the silty clays again represent floors with satisfactorily oxygenated marine waters where brachiopods, trilobites, and mollusks were abundant. Others of these eastern waters may have been inhospitable for the normal life of shallow seas because they were freshened by streams from the eastern land area.

Relations of Trenton and Sub-Trenton at Outcrop in New York, Pennsylvania, and Maryland, with Respect to Oil and Gas Possibilities in Adjoining Subsurface Regions

General considerations

Preliminary suppositions about probable characters of the Trenton-sub-Trenton sediments in their areas of subsurface occurrences in western New York and northern and western Pennsylvania, can be elaborated from the paleogeographic relations and facies trends recognized in the outcrop regions. Implications of the outcrop studies with respect to probable petroleum source beds and reservoir horizons, and thus to oil and gas possibilities of subsurface Trenton and

sub-Trenton sediments of adjoining areas, are considered under the following headings.

General problem of source sediments and reservoir beds
Basement conditions in relation to exploration
Oil and gas possibilities of Lower Cambrian
Oil and gas possibilities of Middle and Upper Cambrian
Oil and gas possibilities of Lower Ordovician
Oil and gas possibilities of Middle Ordovician

It must be recognized that at this stage of information, comments can be offered on only a very tentative and provisional basis.

GENERAL PROBLEM OF SOURCE SEDIMENTS AND RESERVOIR HORIZONS

Regional stratigraphic studies, such as those here summarized for the Trenton and sub-Trenton of New York, Pennsylvania, and Maryland, may contribute significant conclusions about petroleum possibilities since they give information about facies trends of probable source beds, about horizons of potential original porosities, and about depositional and post-depositional tectonic events significant in effects on reservoirs and on petroleum migrations.

Opinions are in conflict about many questions concerning source sediments of petroleum. There is, however, general agreement that special promise is given by near-source, shallow-water suites of clastic marine and estuarine-lagoonal deposits formed under conditions of relatively rapid accumulation. Petroleum occurrences in thick limestone-dolomite sequences indicate that shallow-water marine carbonates may likewise be significant as source horizons.

Potential reservoir horizons giving promise of porosity because of features of original deposition, primarily include well washed near-shore marine and estuarine-lagoonal sheet sands and beach sands. These sediments will tend to possess significant original porosity and permeability, and also are likely to have had favorable association with source sediments rich in organic remains.

Interstitial openings in clastic limestones and coquinas may serve as first-stage reservoirs, but will probably undergo compaction and self-cementation as burial proceeds during subsequent sedimentation.

The tectonic history of the basin during deposition is significant not only because of effects on paleogeography and thus on the characters and geographic distribution of the varying sedimentary facies; but also because local, temporary emergence of parts of the surface of deposition may produce potential reservoir porosities by weathering and leaching of upwarped areas of limestones and dolomites, or of calcareous or dolomitic sands.

The timing of entry of oil and gas into reservoir beds affects the nature, distribution, and maintenance of reservoir porosities.

From Cenozoic petroleum, it is evident that Trenton-sub-Trenton oil and gas must in large part have entered early-stage reservoirs long before the Appalachian folding of Late Paleozoic time. Regional westward and northwestward, updip rise of the early Paleozoics, associated with the pronounced westward con-

vergence of the overlying Paleozoic sediments, must have significantly affected Paleozoic migrations. Migration related to such regional rise was of course modified by any early structural arches associated with the depositional history of the region, as well as by patterns of permeability associated with deposition, with cementation, and with leaching during emergences.

Once emplaced in a reservoir, the oil and gas accumulations presumably helped to maintain porosities by reducing if not preventing further cementation by ground water. Cementation in adjacent extensions of the same bed, may in some cases have locked the oil and gas in place during subsequent tiltings.

In Pennsylvania and New York, the post-depositional tectonic history of the Appalachian trough region is significant because the changing dips would tend to cause migration from early-stage to late-stage reservoirs. Tectonic effects as well as deep burial probably affected porosities by both compaction and cementation. Tectonic pressures and temperatures have evidently modified the petroleum substances themselves, as well as the containing sediments. However, in view of the known exceptions, the carbon-ratio theory as originally postulated by David White should not be fully accepted as a guide limiting eastward exploration in the Appalachian region.

BASEMENT CONDITIONS IN RELATION TO EXPLORATION

The basement conditions of the Pennsylvania-New York region are of interest in connection with future oil and gas exploration of deep formations partly because of their influence on and relation to geologic structures of the overlying sediments, and partly because of their effects on geophysical prospecting.

So far as is known, the surface of the pre-Cambrian in Pennsylvania, New York, and Maryland did not have erosional relief sufficient in amplitude to produce significant structural features in the overlying Paleozoic sediments. Actual knowledge of the contact relations is, however, restricted to eastern parts of the three states.

In eastern Pennsylvania, it is clear that the surficial parts of the pre-Cambrian were deformed during the Appalachian folding in reasonable accord with the larger folds in the Paleozoic sediments.

If the folding of the Paleozoic sediments during Appalachian deformation was largely a response to plastic shortening of the basement in the fashion discussed in an earlier chapter, it is probable that the surface of the pre-Cambrian generally is arched under the major anticlines, depressed under corresponding synclines.

There is some evidence that various Appalachian folds were incipiently active during Paleozoic sedimentation. If this assumption is correct, the incipient activity may well have resulted from stresses active in the basement. Whatever the ultimate cause, any fold activity accompanying sedimentation would be significant in relation to reservoir possibilities.

In their areas of exposure, the pre-Cambrian rocks of New York, Pennsylvania, and Maryland are geologically complex. Throughout the region of the

three states, similar geologic complexity can be expected. The geologic complexities will probably be reflected in both magnetic and gravimetric types of geophysical surveys.

The largest gravimetric anomaly of the New York, Pennsylvania region is a great low paralleling the eastern part of the belt of the folded Appalachians along or northwest of the Hagerstown-Harrisburg-Allentown Valley and its continuations. This major low may be associated with plastic thickening, during the Appalachian deformation, of a basement mass lighter than subjacent rock materials.

Next-order gravimetric and probably magnetic anomalies will probably be associated with large-scale geologic complexities of pre-Cambrian rocks of the surficial parts of the basement. In some areas, especially near Philadelphia and Baltimore, there are igneous bodies of probable Late Paleozoic age that may be large enough to cause significant anomalies, and along the Triassic belt crossing the southeastern part of Pennsylvania there are extensive Triassic diabases. Some small basic intrusives of uncertain age occur in western Pennsylvania.

Geophysical anomalies reflecting the small-amplitude folds west of the Appalachian front will probably be small in value and difficult to distinguish with reasonable confidence.

OIL AND GAS POSSIBILITIES OF LOWER CAMBRIAN

Oil and gas possibilities of the Lower Cambrian sediments of the Pennsylvania-New York region are affected by (1) geographic distribution of the sediments; (2) changes in regional metamorphism; (3) facies in relation to source and reservoir conditions; (4) general structural conditions and depths of burial.

So far as can be judged from present information, Lower Cambrian sediments are probably restricted in New York to the vicinity of the Hudson River Valley; in Pennsylvania they reach their greatest known thickness in the south-central part of the state; they plausibly thin toward the west, northwest, and north in their regions of subsurface extent, and it is improbable that they reach the northern and western borders of Pennsylvania.

In their outcrop regions in south-central and southeastern Pennsylvania, the Lower Cambrian sediments show the effects of low-grade but well defined regional metamorphism. Structural relations of planes of schistosity indicate that much if not all of the metamorphism accompanied the Late Paleozoic Appalachian folding. The Appalachian metamorphism can be expected to decrease in intensity toward the west and north, with consequent waning of its tendency to dissipate Paleozoic accumulations of oil and gas.

The Lower Cambrian sediments of the South Mountains region of south-central Pennsylvania, and of outcrop belts farther east, include thick sand deposits that at the time of deposition should have had favorable reservoir-type porosities. Direction of sedimentary transport at the time of accumulation of these sands is not wholly clear, but derivation seems to have been from the south-

east. If this view is correct, the sand formations should thin and become finer-grained toward the west and northwest. It is not impossible that near the northwesterly margin of the Lower Cambrian trough there may be sand bodies derived from land surfaces on the north and northwest.

Carbonates and some sandy sediments of the upper fourth of the Lower Cambrian in south-central Pennsylvania contain marine fossil faunas. The well washed character and wide extent of some of the underlying sands suggest deposition in shallow marginal regions of the Lower Cambrian seas. Some other parts of the Lower Cambrian sands, silts, and gravels may be alluvial. Marine-estuarine sediments of promise as source and reservoir beds probably continue in the western and northern, subsurface extensions of the Lower Cambrian sediments, but evidence is meager.

Structurally, the Cambro-Ordovician strata exposed in Nittany Valley and Morrison Cove in central Pennsylvania, plunge westward and northwestward deep beneath the younger strata of the Allegheny Front and Allegheny Plateau region. Along the Front, the expected depth of the Lower Cambrian sediments is about 20,000 feet. Toward the west, northwest, and north in Pennsylvania, the depth of the thinning, marginal parts of the Lower Cambrian is expected to lessen in accordance with the well marked convergence of the overlying Paleozoic strata. At Bradford, Pennsylvania, the depth of the horizon of the Lower Cambrian is probably 10,000–12,000 feet, though it is less clear that Lower Cambrian sediments can be expected to extend to this geographic area.

The expected updip pinch-out of the Lower Cambrian in western and northern Pennsylvania could provide significant stratigraphic traps, if porosities have not been too greatly reduced, and if the oil and gas have not been dispersed or destroyed by the combination of deep burial and the heat and stresses of the Appalachian mountain-making.

In summary, Lower Cambrian sediments and hence any possibilities of Lower Cambrian oil and gas probably are restricted in New York to a belt adjacent to the Hudson River Valley. In Pennsylvania, Lower Cambrian sediments should lie at depths of 20,000 feet for some distance west of the Allegheny Front, well below levels of probable exploration for a considerable time to come. With convergence of overlying strata, the Lower Cambrian sediments rise to lesser depths toward the north, northwest, and west, and probably thin and disappear before reaching the northern and western boundaries of Pennsylvania. This updip wedge-out of the Lower Cambrian may provide structural conditions favorable for stratigraphic traps; but the expected depths would make exploration costly.

In the folded Appalachian area of central Pennsylvania, there are various anticlinal axes where the Lower Cambrian can be expected to occur in considerable thicknesses and at depths that are not excessive for drilling. Metamorphism should be less than in the outcrop areas of the South Mountains and more eastern parts of Pennsylvania, but the effects of Appalachian deformation

may still be significant in limiting the oil and gas possibilities of the strata. Reservoir possibilities, if present, must be sought in fracture complexes or in sandstone pockets protected from cementation by contained oil and gas.

OIL AND GAS POSSIBILITIES OF MIDDLE AND UPPER CAMBRIAN

In contrast to the other Trenton-sub-Trenton strata of the Pennsylvania-New York region, the Middle and Upper Cambrian sediments include extensive bodies of quartzose sands believed to have been derived from the north and northwest. These sands therefore probably thicken in the region of their subsurface extension northwest and north of the Appalachian Front of central Pennsylvania, affording possibilities of significant reservoirs.

The sandy sediments of the Middle and Upper Cambrian strata of central Pennsylvania occur chiefly in the Gatesburg formation, with two thin, local sandstone bodies in the subjacent Warrior limestone. The Gatesburg sandstones are interbedded with dolomites; they consist of cleanly washed quartz sand with some feldspar, and in large part are probably dolomitic where unweathered. The sandstones and the predominating dolomites were deposited in shallow waters fluctuating in depth, and in their northwestern subsurface extensions may include bodies that suffered temporary emergence with improvement of porosities by leaching.

Like the Lower Cambrian strata beneath them, the Middle and Upper Cambrian formations plunge from surface or near-surface levels along Nittany Valley and Morrison Cove in central Pennsylvania, to depths of 15,000 and possibly 20,000 feet in the near-by region of the Allegheny Front. They should remain at great depths for some distance west and northwest of the Front, and in this belt assumably are arched by the northern parts of the Laurel Hill and Chestnut Ridge anticlines. Farther west and northwest they are expected to rise in accordance with convergence of the overlying younger strata, the gentle updip gradient modified by various anticlinal and synclinal folds that decrease in amplitude northwestward across the strike.

The northwestward convergence of the post-Cambrian Paleozoic sediments of western Pennsylvania is well marked, and is sufficient to suggest that the Upper Cambrian deposits had a distinct northwestward regional rise well before the time of Appalachian folding. Insofar as this regional rise was not significantly interrupted by early-stage arches, and to the extent that permeability of the reservoir beds were continuous across the area, extensive updip migrations of oil and gas probably occurred, with loss of these substances from the deeper areas. If on the other hand, there were significant early-stage arches, or if permeability patterns of deposition, leaching, or cementation caused retention of the oil and gas in localized regions, then migration up the regional rise would be less significant. In any event, distribution of any oil or gas remaining to-day in the Middle and Upper Cambrian of western Pennsylvania must have been greatly affected by the history of these sediments prior to the time of Appalachian folding.

Although the Middle and Upper Cambrian strata rise west of the Allegheny Front in Pennsylvania in accord with the convergence of younger strata, they remain at depths where exploration will be costly. Near Bradford their upper surface is probably about 10,000 feet below ground level. They rise to shallower levels northward across the western part of New York.

The interbedded dolomites and sandstones of the Gatesburg formation of central Pennsylvania find their facies counterparts in the Theresa deposits of the southern and northern margins of the Adirondacks, and are the approximate age equivalents of the Theresa and associated Potsdam formations. Sandy dolomitic rocks of Potsdam-Theresa age probably underlie much of the region south of the Adirondacks and west of the Hudson River Valley in New York. They are expected to wedge out updip above the surface of the pre-Cambrian in the general vicinity of the southwestern margin of the Adirondacks, where all of the Cambrian strata are absent by unconformity.

Sandy phases of the Middle and Upper Cambrian have fair promise for oil or at least gas in western New York and north-central, northwestern, and western Pennsylvania. In regions where folds are strong enough to give promise of some structural control of reservoirs, the Middle and Upper Cambrian sediments generally occur at depths of 10,000 feet and more. In shallower depths of occurrence, there will generally be lack of structural control and necessity of search for stratigraphic traps alone.

In central Pennsylvania, the Gatesburg dolomite-sandstone formation is breached by erosion in the anticlines of Nittany Valley and Morrison and Friends Coves. It lies below ground and may deserve testing along the axes of some other anticlines in the region.

OIL AND GAS POSSIBILITIES OF LOWER ORDOVICIAN

The Lower Ordovician sediments of the Nittany Valley region of central Pennsylvania comprise a 3,000- to 4,000-foot succession, composed three-fourths of dolomites and one-fourth of limestones. There is one locally developed body of quartzitic sandstone, ranging to nearly 20 feet in thickness.

The border lands of the Appalachian platform of deposition, including the emergent area of the Adirondack region, seem to have been low in altitude during Beekmantown time. Accordingly, it does not seem probable that large bodies of sandstone will be found in the Beekmantown sediments in their regions of subsurface extent through western New York and northern and western Pennsylvania. There may of course be minor tongues and lenses of sand washed from the north in a manner reminiscent of Upper Cambrian paleogeography.

The thin sandstone of the upper part of the Beekmantown near Bellefonte, and some thin sandstones in the Beekmantown near Chambersburg, reflect activity of the platform of deposition during Beekmantown time. There has been some suggestion that the thin sandstone near Bellefonte may be a tongue from the widespread Chazyan St. Peter sandstone of the northern Mississippi Valley

region. The age correlation and source-direction of the sandstone near Bellefonte are not yet closely enough established to furnish a final answer to this problem. Krynine has, however, published petrologic evidence that elements of the sandstone near Bellefonte were derived from upwarped Upper Cambrian Gatesburg sandy dolomite, or its petrographically similar continuations.

In the subsurface areas north and northwest of the Nittany Valley region of central Pennsylvania, the Beekmantown sediments probably thin like those shown in Figure 20. The thinned parts may represent less continuous deposition and, if so, were probably affected by local emergence and weathering during parts of Beekmantown time. If such emergence and weathering did occur, favorable reservoir-type porosites may have been developed locally by solution and leaching of the Beekmantown strata. Where the Beekmantown is thin, and uparching favorable, breaching of the Beekmantown may have uncovered limited areas of the sandy Gatesburg.

Oil and gas possibilities of porous zones developed by local emergence and leaching of the Beekmantown would be greatly enhanced if the lines of emergence followed axes inherited by anticlines of the Appalachian folding.

The proportion of dolomite versus limestone in the Beekmantown succession is greater in central than in southeastern Pennsylvania. This regional change favors the view that the Beekmantown deposits are probably predominantly dolomites rather than limestones in the subsurface areas of western and northern Pennsylvania and western New York.

It is reasonably clear that the dolomitization of the Beekmantown of central Pennsylvania is in general paradepositional, and not related to surfaces of unconformity. The extensive dolomitization of the Beekmantown strata in Nittany Valley is not connected with known large-scale slump structures antedating the present erosional cycle, and is not plausibly a source of significant shrinkage porosity. Porosity might, however, be developed in dolomites and dolomitic limestones by differential leaching of limestone constituents during emergence and exposure to weathering.

The fine-textured Bellefonte dolomite of the upper Beekmantown of Nittany Valley is cut by more numerous joints than are most adjoining formations. Assumably the joints are related to Appalachian folding and if so would not have furnished early-stage reservoir porosities.

The coarser-textured beds of the Nittany dolomite, below the middle of the Beekmantown in Nittany Valley, have vug-like cavities, some open for several hundred feet below the surface where cut by well cores. Permeability of the walls of the vugs is low.

In summary, it appears that any significant reservoir porosities in the northwestward, subsurface extensions of the Beekmantown are probably to be dependant on uparching, leaching, and erosion related to unconformities. Some sandstones may be present, either as thin tongues brought in from northerly marginal lands or as lenses bordering upwarped and eroded areas of the pre-Beekmantown

Gatesburg strata. Vugs occur in the Nittany dolomite, but may not be numerous enough or well enough connected to provide important reservoir porosities. Some fracture porosity is present in the fine-textured Bellefonte dolomite, but was not available for early-stage migrations.

OIL AND GAS POSSIBILITIES OF MIDDLE ORDOVICIAN

Through their subsurface areas in south-central and southwestern New York and northern and western Pennsylvania, the Middle Ordovician Chazy, Black River, and Trenton sediments mostly are limestones.

Some shales occur at the top of the Trenton even in the western parts of the region, if Kay's usage is employed for the group.

East of a line from Little Falls, New York, along a path east of Nittany Valley but west of Chambersburg in Pennsylvania, the limestones of the middle and late parts of Trenton time pass laterally into clay shales. Still farther east, the shales contain increasing quantities of silt and some sand.

Even in the most easterly Trenton-age sediments of the subsurface areas in New York and Pennsylvania, it is improbable that sandstones occur in bodies sufficient to serve as significant reservoirs. The late Martinsburg sandstones of eastern Pennsylvania probably are post-Trenton in age.

Favorable reservoir conditions in the Chazy, Black River, and Trenton sediments of New York and Pennsylvania are hence dependent on features of the limestone sediments.

Disconformities occur at several horizons in the Chazy, Black River, and Trenton limestones in their outcrop areas in north-central New York and central Pennsylvania.

It is probable that the disconformities observed in the outcrop belts are persistent in the subsurface areas farther west. The emergent stages represented by the disconformities may at places be associated with solution and solution-slump features that could serve as reservoirs. If dolomitization occurred in any of the zones of weathering, local shrinkage porosities may have been formed.

Porosities produced by solution and weathering will be difficult to locate unless they are related to arches which were weakly active during the general period of deposition, and which by structural inheritance are reasonably coincident with present anticlinal axes. Though present evidence is inadequate, especially for the older and deeper strata, the possibility of early crustal activity along present anticlines will merit consideration in any future plans for deep tests.

Some of the natural-gas occurrences in Trenton limestones in central New York seem to be related to the trapping action of shale interlayers. Shale interlayers can be expected in higher parts of the Trenton limestones of subsurface areas in New York and Pennsylvania, even if the limestone-shale boundary is transgressive in age.

Commercial production of natural gas in the Trenton limestone in central

New York gives some promise for occurrences in the Middle Ordovician limestones in southern New York and Pennsylvania. The increased depths in these southern areas will of course greatly increase costs of exploration and production.

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VOL. 32, NO. 8 (AUGUST, 1948), PP. 1596-1626, 7 FIGS., 1 TABLE

TRENTON AND SUB-TRENTON STRATIGRAPHY OF NORTHWEST BELTS OF VIRGINIA AND TENNESSEE[1]

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ABSTRACT

The Lower Cambrian Rome is the oldest formation exposed in the northwest belts of Virginia and Tennessee. The formation consists of thick clastics, the shales apparently serving as the loci of thrusting along several of the northwest thrust blocks of Tennessee. The overlying Conasauga group, largely shale northwest in Tennessee, grades through shales and limestones into dolomitic limestones and dolomite southeast and east, reflecting a general northwestward to westward source. Analyses of the more persistent sandstone units at the top of the overlying Copper Ridge dolomite suggest a similar source direction. The Copper Ridge (Upper Cambrian) and Beekmantown (Lower Ordovician) dolomites grade southeastward into limestones, the gradation isoliths closely coinciding with a structural barrier of some nature. This barrier is presumably an arch ("Tazewell arch") quite similar to, and probably an extension of, the Adirondack arch on the northeast, and possibly is in part coincident with the Rome barrier of Ulrich. The trend of the Tazewell arch coincides closely with the present position of Clinch Mountain in Virginia and Tennessee. The Saltville thrust closely outlines the trend of the arch along the southeast flank.

Middle Ordovician rocks southeast of the Tazewell arch are thick and highly clastic, indicating a rejuvenation of the landmass source on the southeast and an accompanying shift in the source direction to the southeast. The Tazewell arch was particularly effective in separating typically geosynclinal rocks from the foreland rocks on the northwest, being more effective in Tennessee than in Virginia. Pre-Trenton, post-Beekmantown units thin by convergence and overlap from approximately 4,600 feet southeast of the arch (southeast of Knoxville, Tennessee) to approximately 1,000 feet northwest of the arch near the Kentucky-Tennessee line. The same interval thins along the strike of the foreland rocks from 1,400 feet in Lee County, Virginia, to approximately 500 feet in Pendleton County, West Virginia. Isopachs of this interval are fairly closely parallel with the Tazewell-Adirondack axis trend.

Recent oil developments in the area of the Cumberland thrust block in Lee County, Virginia, have created additional interest in the northwest outcrop belts. Oil has been produced from the Trenton, Eggleston, and "Lowville" limestones, with a showing from the Beekmantown dolomite. The rock porosity is not well understood. Field indications suggest fracture porosity.

INTRODUCTION

The area under discussion is in the Appalachian Valley and Ridge province. It extends along the valley from northern Virginia to a point near Knoxville, Tennessee, and across the valley from Clinch Mountain and the Saltville thrust to the Cumberland-Allegheny Front.

Cambrian and Ordovician rocks are exposed extensively throughout the area. Recent study has been confined largely to the Middle Ordovician rocks.[3] The Upper Cambrian and Lower Ordovician, consisting chiefly of massive dolomites, may be correlated in a general way but no satisfactory basis for the subdivision of these rocks in the entire area has been found. Middle Cambrian rocks crop

[1] Manuscript received, February 28, 1948.

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[3] C. E. Prouty, "Lower Middle Ordovician of Southwest Virginia and Northeast Tennessee," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 30 (1946), pp. 1140–91.

out only in small isolated exposures. Lower Cambrian rocks beneath the Rome shale are nowhere exposed.

STRATIGRAPHY

The rocks autochthonous to the Saltville thrust in Tennessee occur along several outcrop belts which represent repetition of the strata by thrust faulting or folding. The belts contain rocks having a general northeastward strike and varying dips northwest or southeast. Traced northeastward from Tennessee these belts occur in southeastern West Virginia and northwestern Virginia and extend into Pennsylvania and New York in the area northwest of the Adirondack axis.

CAMBRIAN SYSTEM

Pre-Copper Ridge units.—The oldest rocks exposed northwest of Clinch Mountain are late Lower Cambrian in age (Rome formation). Earlier Lower Cambrian rocks are well exposed southeast of Clinch Mountain including the Chilhowie series, Antietam, and Shady equivalents. The distribution of these units beneath the Rome in the northwest belts is questionable as the base of the Rome formation is nowhere exposed in that area. The Rome occurs in four of the northwest belts in Tennessee and along one important belt in southwest Virginia. The base is in most places truncated by the several thrust faults which have placed the Rome opposite beds as young as Mississippian in age. The thickness of the Rome can only be estimated in the northwest belts because of the unexposed base and the crimpled strata. Estimates of its thickness in most places are between 1,000 and 1,500 feet. The formation consists of vari-colored shales, sandstones, and a little limestone throughout most of the area. The siliceous nature of the shales and the red color differentiate the Rome from the various units of the Conasauga group above. The distribution and character of the Rome formation are reviewed by Butts[4]

The Conasauga group overlies the Rome formation with apparent conformity in all places observed. This group, containing units of Middle and Upper Cambrian age, consists chiefly of undifferentiated shales in the northwest belts of the valley in Tennessee and grades eastward and southeastward into units which may be differentiated, in ascending order, into the Rutledge limestone, Rogersville shale, Maryville limestone, and Nolichucky shale (Fig. 2). The Rogersville shale grades into more calcareous beds northeastward in Virginia where the Rutledge, Rogersville, and Maryville are grouped together as the Honaker limestone, the latter becoming more magnesian on the northeast and finally becoming dolomite in places. The Elbrook limestone, named from Pennsylvania, is considered essentially the equivalent of the Honaker.[5] The formation has been mapped by Butts in

[4] Charles Butts, "Geology of the Appalachian Valley in Virginia," *Virginia Geol. Survey Bull. 52* (1942).

[5] C. E. Resser, "Cambrian System (Restricted) of the Southern Appalachian," *Geol. Soc. America Spec. Paper 15* (1938), p. 11.

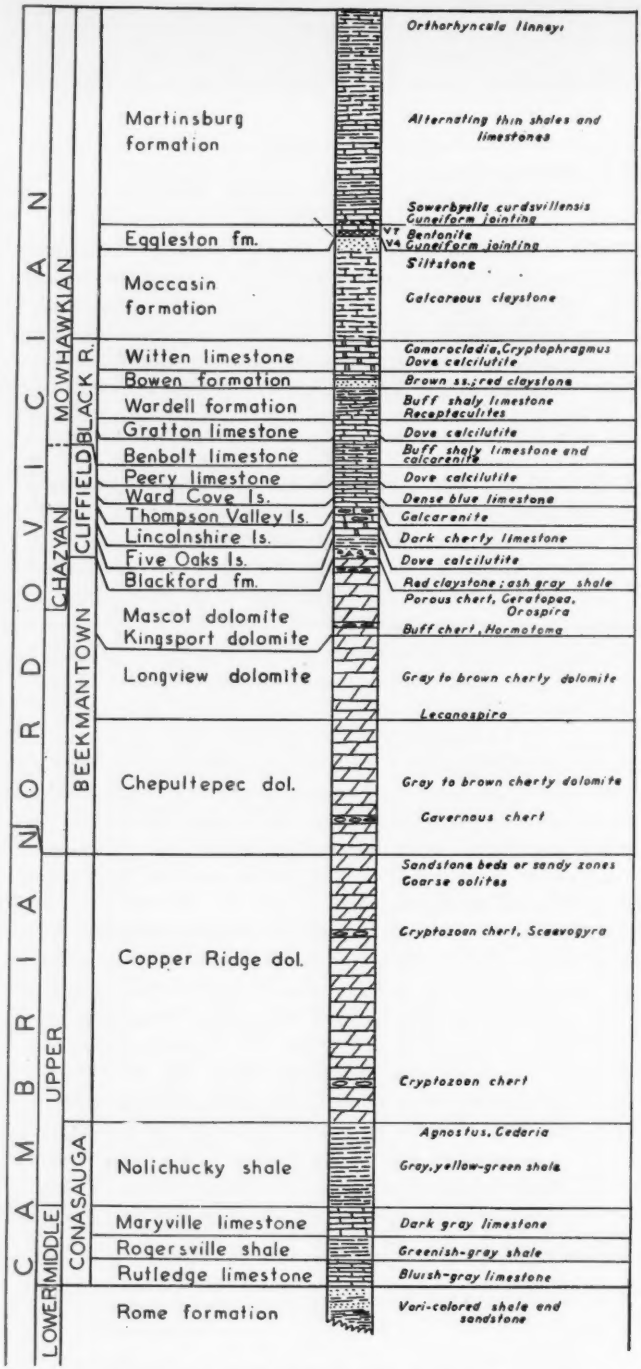

FIG. 1.—Generalized section of Trenton and older rocks of northwest belts of Virginia and Tennessee.

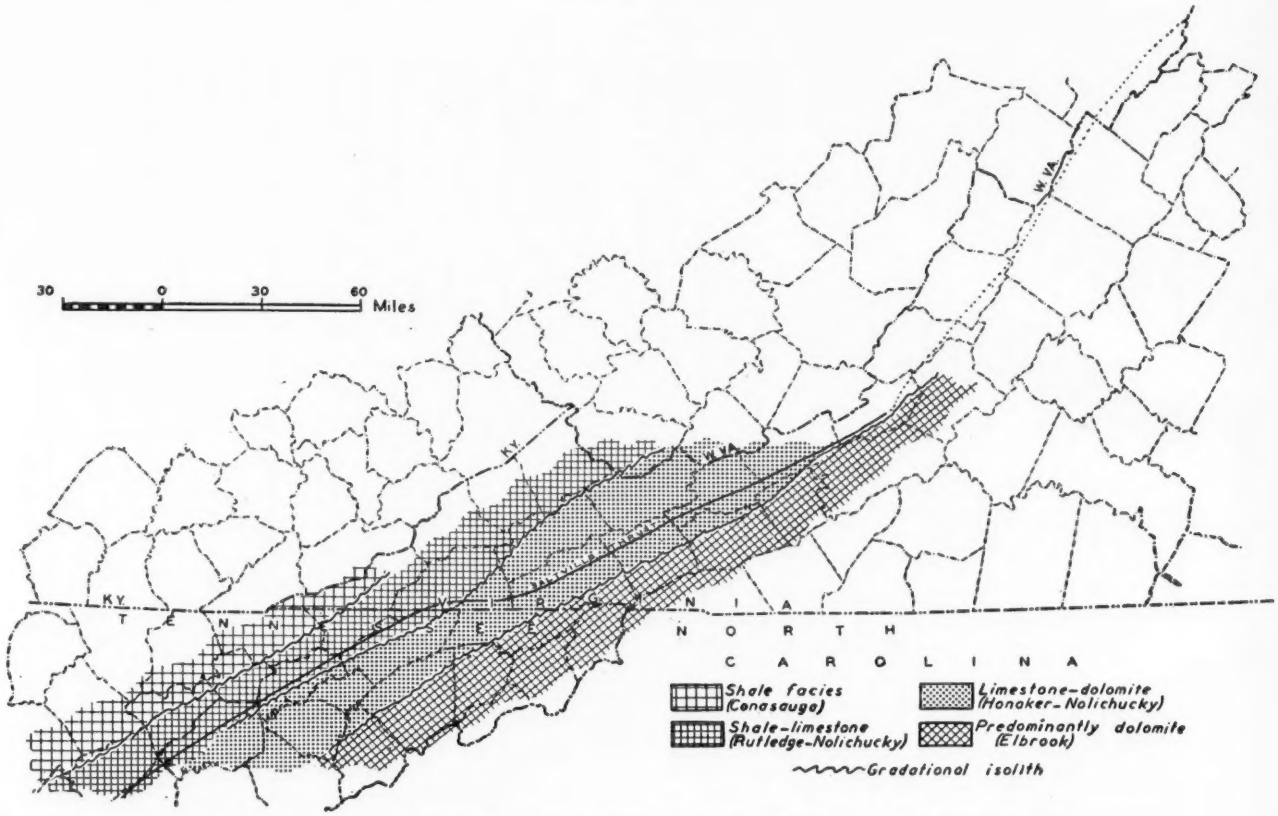

FIG. 2.—Map showing facies variation in Middle and Upper Cambrian rocks of southwest Virginia and northeast Tennessee.

the southeast belts of Virginia where he includes the Nolichucky shale in the top of the Elbrook.

The Nolichucky shale overlies the Honaker limestone, or the Maryville limestone where the Honaker may be differentiated. The contact is in places gradational. The Nolichucky is commonly very calcareous, becoming thin-bedded, laminated limestone at the top. This unit has been called the Maynardville limestone by Oder[6] and considered a separate formation between the Nolichucky and Copper Ridge. Transitional relationship between the limestone and lower shales has led many, including the writer, to consider the former a part of the Nolichucky. The Nolichucky thins northeastward along the belts in Virginia, disappearing along the most northwesterly belt in Tazewell County, and along median belts in Giles County.[7] The presence of the zone in northern Virginia is questionable, but Resser[8] describes fossils from the Warrior limestone of central Pennsylvania common to the upper Nolichucky, indicating a homotaxial relationship of the two formations.

Copper Ridge dolomite.—The Copper Ridge dolomite[9] overlies the Conasauga shale in northeast Tennessee or, where the latter is differentiated, it overlies the Nolichucky shale. The basal relationship appears conformable but the Brierfield, Ketona, and Bibb dolomites[10] are thought to occupy this interval in Alabama, indicating a possible hiatus of considerable proportions beneath the Copper Ridge of Tennessee and Virginia.

The Copper Ridge occurs along the northwest belts in Virginia and Tennessee, the limestone equivalent (Conococheague) occurring in the southeast belts, essentially south of the Saltville thrust. The Conococheague in its type region in southern Pennsylvania[11] underlies the Beekmantown and overlies the Elbrook. The Elbrook as generally mapped in the southeast belts of Virginia contains the Nolichucky equivalents at the top and is thought by Resser[12] to differ from the type Elbrook in Pennsylvania in that Nolichucky equivalents are absent from the latter. The Copper Ridge of the northwest and medial belts of Virginia and Tennessee overlies the Nolichucky or Conasauga and underlies the Beekmantown and would therefore have the same stratigraphic position as the Conococheague

[6] C. R. L. Oder, "Preliminary Subdivision of the Knox Dolomite in East Tennessee," *Jour. Geol.*, Vol. 42 (1934), p. 475.

[7] Charles Butts, *op. cit*, p. 83.

[8] C. E. Resser, *op. cit.*, p. 21.

[9] E. O. Ulrich, "Revision of the Paleozoic Systems," *Bull. Geol. Soc. America*, Vol. 21 (1911), p. 548.

[10] E. O. Ulrich, *ibid.*, pp. 628, 633–34.
Charles Butts, *Alabama Geol. Survey Spec. Rept. 14* (1926), p. 83.

[11] G. W. Stose, "The Cambro-Ordovician Limestones of the Appalachian Valley in Southern Pennsylvania," *Jour. Geol.*, Vol. 16 (1908), p. 701.

[12] C. E. Resser, *op. cit.*, p. 11.

as mapped by Butts[13] in the southeast belts of Virginia. The lower contact of the Copper Ridge, however, would be younger than that of the type Conococheague. The Copper Ridge has the same stratigraphic position as the Gatesburg formation of central Pennsylvania, the latter overlying the Warrior limestone, homotaxial with the Nolichucky, and the upper part (Mines dolomite) underlying the Larke dolomite (Beekmantown). Interesting comparisons lithologically include sandstone zones and siliceous oölites occurring in both.

The Copper Ridge dolomite is not exposed in the western belts of Virginia northeast of Sinking Creek Valley, Giles County. The northeast extensions of these belts (Bolar, Warm Springs, and Crabbottom valleys in Virginia; and Wills Mountain in West Virginia) have no exposures older than Beekmantown in age. In the area autochthonous to the Saltville thrust, the Copper Ridge dolomite crops out principally along two sub-parallel linear belts extending from southwest Virginia throughout Tennessee. The character of the dolomite is remarkably persistent over very broad areas along the strike of the belts, contrasting readily to the relatively rapid southeastward gradation into the calcareous Conococheague equivalent of the southeast belts, illustrating the near parallelism of the isoliths with the outcrop belts (Fig. 3). The gradational isolith coincides fairly closely with a facies barrier, probably the same barrier of considerable importance during the Middle Ordovician, to be considered later. The chief variation of a directional nature is noticeable in the general increase in the chert content southwest from Virginia to Tennessee. Local variations are most noticeable in the occurrence of sandy zones within the dolomite. Nearly every large exposure shows one or more sandy zones which may vary from a few inches to several feet in thickness. These zones occur at various horizons throughout the formation in Virginia and Tennessee, a feature likewise common to the equivalent Gatesburg of Pennsylvania and Conococheague of Virginia and Pennsylvania. Though thin sandy zones occur throughout the Copper Ridge, only those near the top of the formation are sufficiently thick and persistent to be noteworthy.

The sandstones of the Copper Ridge are of considerable interest because of their local importance in mapping. The occurrence of the sand in sufficient concentration to form sandstone beds or highly sandy layers is important in differentiating the Copper Ridge from the highly similar Beekmantown dolomites above. The sandstones likewise are important in determining the local structure of the dolomite in that they are the most readily recognized units within the homogeneous dolomite. Further current interest is shown in the sandy zones regarding their occurrence and origin. The sandy zones represent the major changes throughout the deposition of several hundred feet of dolomite. Thin shaly beds occur in places but the sandy zones generally pass directly into dolomite. The sandstones appear to be fairly uniform in character in the entire area; a few generalizations follow.

[13] Charles Butts, "Geologic Map of the Appalachian Valley of Virginia," *Virginia Geol. Survey Bull. 42* (1933).

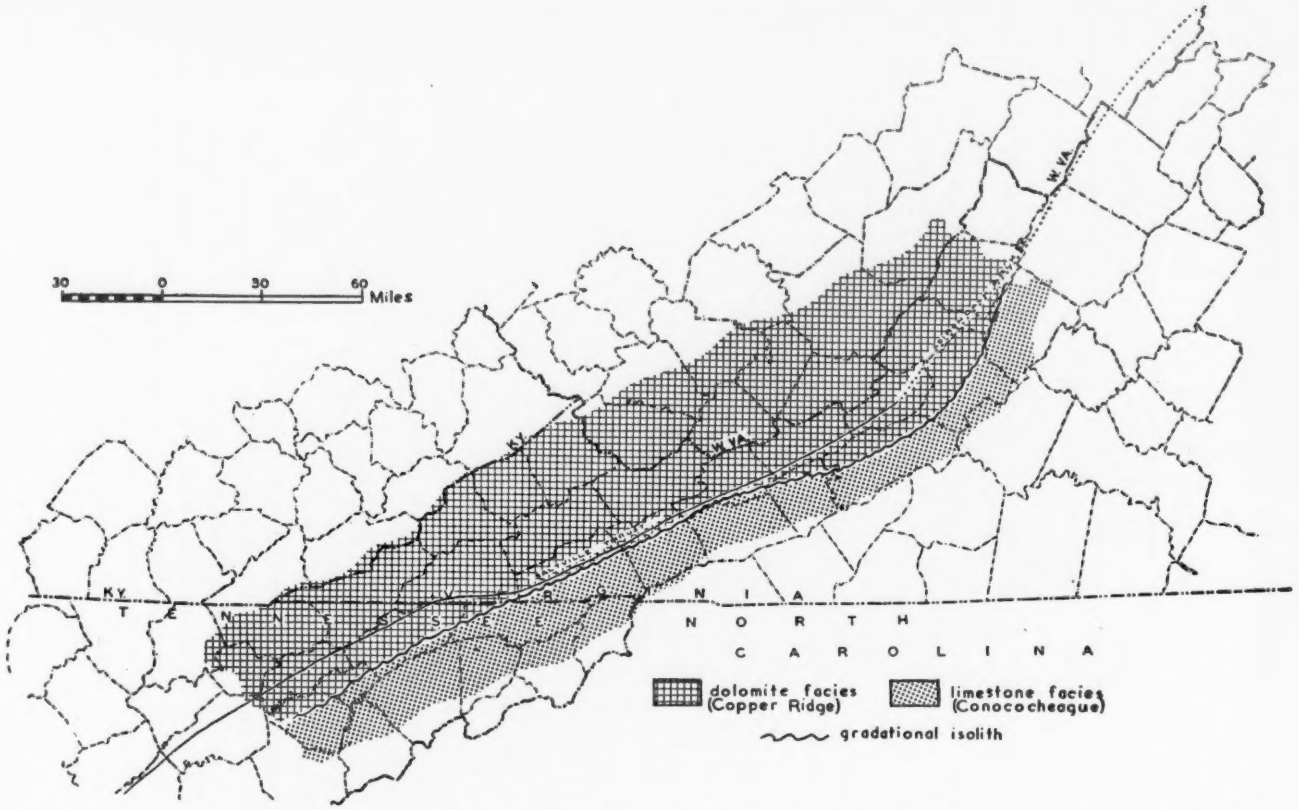

FIG. 3.—Facies map of Copper Ridge dolomite and Conococheague limestone equivalent, showing proximity of gradational isolith to Adirondack line.

1. The sandstones generally have dolomitic cementing material but may have a siliceous cement producing essentially a quartzite.

2. The sandstones show indications of shallow-water deposition, ripple marks and cross-bedding being common. Mudcracks were observed in places.

3. Little persistent directional thickening or thinning is shown over broad areas.

4. Most of the sandstone beds occur in the upper few hundred feet of the dolomite, though lower beds may be well developed in certain areas.

5. Heavy minerals from the sandstones consist chiefly of well rounded tourmaline, zircon, leucoxene, and rutile.

6. The quartz sand commonly shows considerable authigenic silica development.

7. Though most of the sandstone beds are traceable for only a few miles, in some areas a few of the more persistent zones extend at least 30 or 40 miles in other areas.

Sedimentary analyses of two such persistent sandstones were made in the Norris Reservoir region of Tennessee.[14] This is a region of more than 700 square miles, after considerable shortening along the Wallen Valley, St. Paul, and Clinchport faults and also shortening by small-scale as well as broad folding (Powell Valley anticline). Two sandstone beds near the contact of the Copper Ridge and Chepultepec were sampled along the strike of the various fault blocks and likewise across the belts. The two beds varied from 3 to 10 feet in thickness but maintained a fairly constant separating interval of 15–20 feet. The two beds were differentiated from other thinner sandstones on the bases of thickness and interval. The principal findings based on textural, petrographic, and mineralogic analyses indicate the following.

1. The steady westward and northwestward increase in grain size in the two sandstones suggests a west-northwest source.

2. The occurrence of the sandstones suggests deposition under normal marine conditions in a shallow sea.

3. The authigenic silica overgrowths on the sand grains seem to represent penecontemporaneous development from concentrated silica solutions at or soon after deposition. The silica and dolomite cementing material seems to have developed penecontemporaneously with sedimentation.

4. There is no definite evidence that the sandstones have undergone more than one cycle of sedimentation.

The possibility of a westward source for the sand supports the conclusions indicated for the Middle Cambrian (Conasauga equivalents). The source for such sediments involves interesting speculation.

Though the sandstone beds represent the most distinctive variation in the Copper Ridge, several other characteristic features occur. Siliceous oölites and

[14] C. E. Prouty, "Sedimentary Analyses of Cambro-Ordovician Sandstones in Northeast Tennessee." *Manuscript* (1947).

FIG. 3.—Facies map of Copper Ridge dolomite and Conococheague limestone equivalent, showing proximity of gradational isolith to Adirondack line.

oölitic chert occur here and there throughout the entire dolomite. A particularly well developed zone of coarse oölitic chert occurs 50-100 feet below the well developed sandstone at the top of the Copper Ridge in much of northeast Tennessee. It is not certain that this represents the same bed everywhere but its stratigraphic position and lithologic character suggest this. Chert occurs in large gnarly masses throughout the dolomite. A few of these beds appear persistently in broad areas. One such zone in northeast Tennessee occurs 450–550 feet beneath the lowest prominent sandstone of the upper Copper Ridge. This zone commonly contains *Scaevogyra* cf. *S. sweezyi* and cryptozoan sp., occurring in reef-like masses. Another zone of a smaller cryptozoan chert commonly occurs 250–350 feet above the base of the formation.

Dark shaly beds occur commonly throughout the Copper Ridge, though quantitatively they form only a small part of the formation. Most of the shale occurs in thin laminations or shaly partings. In northeast Tennessee greenish gray to dark brown shales as much as a foot thick are associated with the upper sandstone beds. The dolomite, ordinarily gray to brownish gray, commonly becomes dark in color, apparently due in part to the higher concentration of hydrocarbons. The dolomite, on breaking, commonly yields the fetid odor noticeable in the presence of hydrocarbons. Especially is this noticeable in the darker, apparently more bituminous part of the dolomite.

The contacts of the Copper Ridge are not well defined, no definite boundaries being proposed in the original description.[15] The lower contact is readily placed where the Nolichucky shale directly underlies the dolomite. Where limestones ("Maynardville" of Oder) separate the shale from the dolomite, the contact depends on the disposition of the limestones. Resser[16] considers the limestones to represent the top part of the *Blountia* zone of the upper Nolichucky, plus a part of the Copper Ridge, which would imply a transitional relationship between the two. The upper contact is generally placed either above or below the well developed sandstone beds at the top. Though some workers are inclined to assign these to the base of the Chepultepec, it appears more logical to place them in the Copper Ridge as that formation is characteristically siliceous throughout, whereas the Chepultepec has little or no sandstone in most areas. The textural analyses indicate that the various sandstones become coarser upward in the section, a condition perhaps more expected at the end rather than the beginning of a system.

Because of the scarcity of Copper Ridge fossils and the somewhat variable position of the fossil-bearing chert beds a close upper and lower contact can not generally be determined on the basis of fauna alone.

[15] E. O. Ulrich, "Revision of the Paleozoic System," *Bull. Geol. Soc. America*, Vol. 22 (1911), p. 548.

[16] C. E. Resser, "Cambrian System (Restricted) of the Southern Appalachians," *Geol. Soc. Amer. Spec. Paper 15* (1938), p. 18.

ORDOVICIAN SYSTEM

Beekmantown Group.—The rocks belonging to various units of the Beekmantown group are similar lithologically throughout the northwest belts of Virginia and Tennessee. The separation of the units is essentially based on faunal differences. The fossils of the Beekmantown dolomite of Virginia and Tennessee are recovered largely from chert beds which yield this fossil content best from the weathered residual fragments. No fossils have yet been identified from the dolomite itself. For this reason close contacts can not be drawn between various formational units, and the subdivision of the group is impractical for most purposes. The classifications used in Tennessee and Virginia are varied and in general based on long distance homotaxial correlations with formations some of whose boundaries are not well defined in their type regions. Though synchronous units may be established faunally from Virginia and Tennessee to Pennsylvania, Alabama, and Missouri, the lack of persistent lithic and faunal zones make the establishment of definite formational boundaries difficult. The Beekmantown group is here used in a formational sense with mention of the various units where practical.

The lower unit of the Beekmantown, the Chepultepec[17], has been mapped throughout east Tennessee and the southeast belts of Virginia. In east Tennessee the formation is similar to the underlying Copper Ridge with which it appears conformable. The distribution of the Chepultepec is like that of the Copper Ridge excepting that the latter disappears in Virginia along the belts northwest of Clinch Mountain and the Saltville thrust. The Chepultepec changes from predominantly dolomite northwest of this line to predominantly limestone on the southeast (Fig. 4), similar to the distribution of the dolomite and limestone facies of the Copper Ridge-Conococheague previously mentioned. Thus a barrier of some kind is inferred. That the Saltville thrust is not the barrier is demonstrated by the similar facies distribution northeast, along this line after the termination of the Saltville thrust in Craig County, Virginia.

The Chepultepec occurs along all of the northwest belts of northeast Tennessee. The dolomite is generally fine-grained, light to bluish gray, in places pinkish. On weathering it acquires a light to dark brown color. In most respects it closely resembles the underlying Copper Ridge. Chert occurs commonly though perhaps not so plentifully as in the Copper Ridge. The chert is brownish, soft, mealy, and cavernous, ordinarily differentiated by these characteristics from the chert in the Copper Ridge. Few zones occur continuously throughout the Chepultepec of this area. One zone of highly cavernous chert occurs approximately 300 feet above the lowest well developed sand of the upper Copper Ridge. A second thin zone worthy of mention reveals an irregular surface along the bedding, occurring approximately 250 feet above the lowest persistent sandstone of the upper Copper Ridge. The occurrence of angular chert above the

[17] E. O. Ulrich, *op. cit.*, pp. 549, 638.

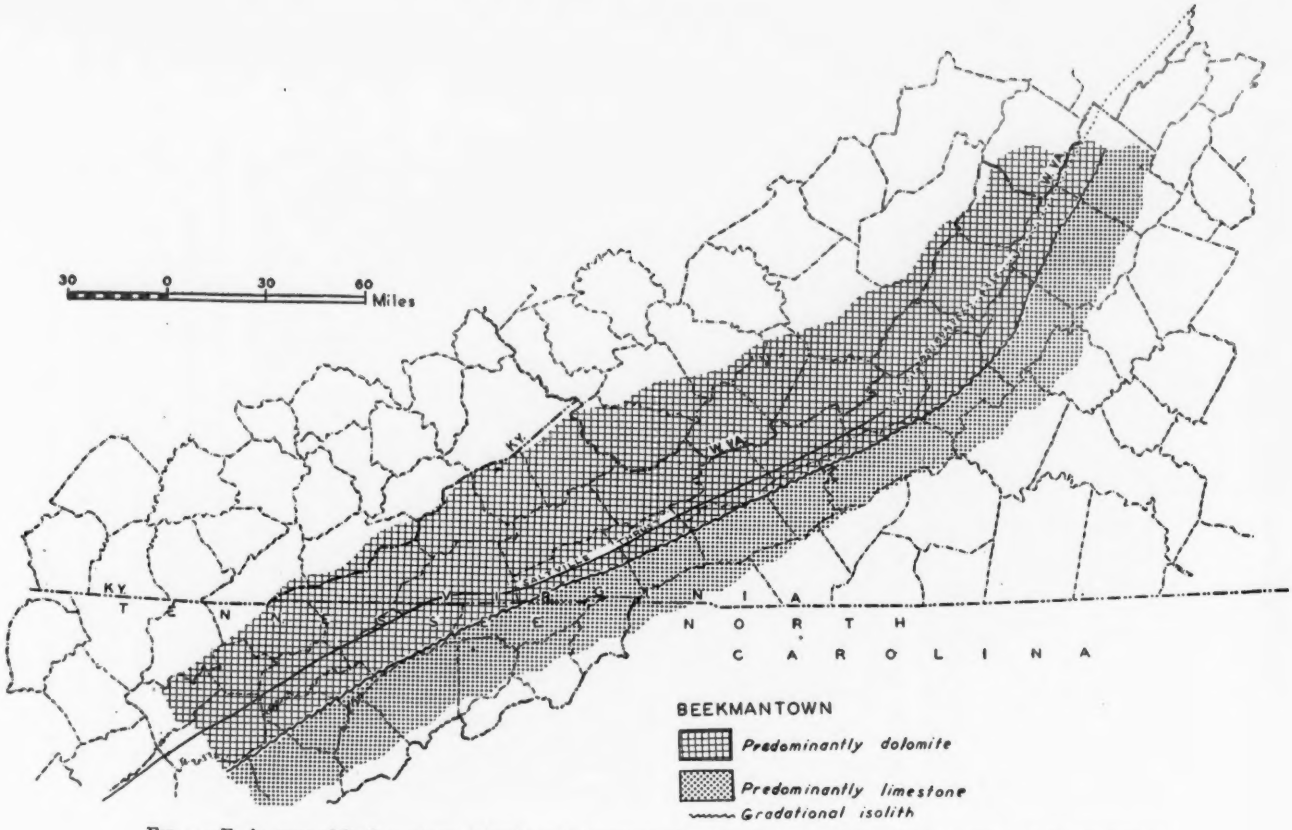

FIG. 4.—Facies map of Beekmantown dolomite and limestone, showing proximity of gradational isolith to Adirondack line.

surface suggests intraformational conglomerate. Siliceous oölites and oölitic chert occur commonly throughout the Chepultepec, but especially in the lower and middle part.

The upper contact of the Chepultepec is not well defined. There is no sharp lithologic break and the boundary is generally placed at random between the last occurrence of Chepultepec fossils and the first appearance of *Lecanospira*. The fact that fossils are largely confined to chert beds also makes it difficult to draw a close contact. The thickness of the Chepultepec averages 700-750 feet in the west belts.

Nolichucky shale.—The Chepultepec has been correlated at least in part with the Van Buren and Gasconade (restricted) of Missouri. The Copper Ridge-Chepultepec sequence shows a remarkable resemblance to the Emminence-Gasconade of Missouri in both lithologic characteristics and fauna. Some fossils of the Chepultepec occur in the Tribes Hill limestone of New York and the Stonehenge of Pennsylvania.

Though fossils are not numerous in the Chepultepec of this area, such diagnostic forms as *Ectenoceras chepultepecensis*, *Helicotoma uniangulata*, *Syntrophinella*, and several species of *Sinuopea* are found.

The *Lecanospira* beds form the second zone of the Beekmantown and are essentially equivalent to the Longview limestone of Alabama. The Longview is largely limestone in the type region and in this sense the name might be used in the southeast belts of Tennessee and Virginia. Northwest of Clinch Mountain the Longview equivalent is largely dolomite and has often been referred to the Nittany dolomite, the approximate equivalent in Pennsylvania. The proper reference of the *Lecanospira* beds in northeast Tennessee and southwest Virginia to either the Nittany or Longview is questioned as the relationships of the lower and lower boundaries of the type Nittany in Pennsylvania and the upper contact of the type Longview of Alabama are indefinite in the Virginia-Tennessee area. In Pennsylvania, the Stonehenge limestone underlies, and the Axemann limestone overlies, the Nittany. The Stonehenge, partially homotaxial with the Chepultepec, apparently becomes dolomitic southwestward and shows indefinite relationship with that formation. The presence of the Axemann in Virginia and Tennessee has not been established. In Alabama the Newala limestone overlies the Longview and though probably a partial equivalent of post-*Lecanospira* dolomites of Tennessee and Virginia, it has different lithologic characteristics and indefinite boundaries in the latter area.

It appears best to dispense with the term Nittany in areas where the relationships with the Stonehenge and Axeman (Bellefonte in the local absence of the Axeman) are indefinite; and to dispense with the term Longview where definite relationship with the Newala is unknown. For this reason a new formational name is needed in northeast Tennessee and southwest Virginia, since redefinition of the Longview or Nittany in that area would not clarify relationships to the type areas of those units. However, additional study is needed and the term Longview might best be tentatively applied.

FIG. 4.—Facies map of Beekmantown dolomite and limestone, showing proximity of gradational isolith to Adirondack line.

The Longview occurs along the northwest belts of Virginia and east Tennessee, where the rocks consist chiefly of dolomite with here and there a thin bed of fairly pure limestone. In northern Virginia the dolomite becomes more calcareous on the southeast, a feature observed more extensively in the Copper Ridge in Virginia and Tennessee and in the Chepultepec in Tennessee. The Longview dolomite occurs in most all of the northwest belts from Sinking Creek valley, Craig County, Virginia, into Tennessee. These beds consist chiefly of light bluish gray to buff dolomite not readily differentiated from the underlying dolomite. The presence, here and there, of limestone beds, however, helps to differentiate the Longview from the Copper Ridge and Chepultepec in the western belts. Chert is common and is generally less mealy and cavernous than that of the Chepultepec. Few if any distinct sandstone beds are developed but sandy dolomite occurs in places. The thickness can not be closely determined but averages fairly close to 200–250 feet throughout the area.

The *Lecanospira* beds have been correlated largely on the gastropod fauna with the Nittany dolomite of Pennsylvania, the Longview dolomite of Alabama, and the Roubidoux formation of Missouri. The general nature of the Nittany and lower dolomites is shown in Table I.

The upper Beekmantown (*Ceratopea* beds) has been identified on the basis of faunal content from New York to Alabama. The beds occur in both northwest and southeast belts in Virginia and Tennessee. *Ceratopea*, or other important fossils from this horizon, have been observed in all the northwest belts of Virginia including Crabbottom, Bolar, and Warm Springs valleys in northwest Virginia. The presence of this zone in Mercer and Monroe counties of West Virginia is questionable. Due to thinness of the *Ceratopea* beds and the pronounced post-Beekmantown erosion, the beds are not continuous along the northwest belts. In the region near Tazewell, Virginia, the *Ceratopea* beds are found only where the thickness of the Beekmantown exceeds approximately 700 feet.[18] In other places erosion has apparently removed the *Ceratopea* beds and cut into the *Lecanospira* beds. This feature is observable at various places along all of the belts. Though close contacts can not be drawn at the base, the thickness of these beds in the Tazewell area hardly exceeds 300 feet, and averages closer to 250 feet. In northeast Tennessee, the *Ceratopea* beds are exposed in all the belts and show little directional change along the strike of the belts from Virginia, with the exception that limestone appears to be more common in Tennessee, a change likewise noticeable southeastward across the belts into the allochthonous sections. The dove-colored compact limestone beds contrast markedly to the gray to buff, coarser-grained dolomite. The limestone ordinarily occurs in thin beds as much as 3 feet in thickness. They are similar to the dense, dove-colored limestones of the lower Middle Ordovician and where they occur together can not be readily

[18] B. N. Cooper, "Geology and Mineral Resources of the Burkes Garden Quadrangle, Virginia," *Virginia Geol. Survey Bull. 60* (1944), p. 32.

TABLE I

SECTION ALONG BIRD CREEK, NORRIS RESERVOIR REGION, TENNESSEE

Description	*Thickness of Unit (Feet)*	*Thickness to Base of Formation (Feet)*
Elevation, 1851 feet		
NITTANY DOLOMITE		
Dolomite, mottled light and dark gray, coarsely crystalline	3.0	275.0
Chert, white, containing *Lecanospira*	1.0	272.0
Dolomite, light and dark gray, mottled	14.0	271.0
Shale, greenish	0.5	257.0
Chert, white, irregular	0.5	256.5
Dolomite, light gray, cryptozoan chert near middle	7.0	256.0
Shale, green	0.7	249.0
Dolomite, thick-bedded, coarsely crystalline, much white chert in basal part	20.0	248.3
Chert, massive, white, large cryptozoan; some coarsely crystalline dolomite and greenish shale	6.0	228.3
Dolomite, coarsely crystalline, light to dark mottled, dense, white chert 1.5 ft. thick, 5 ft. from top; two greenish shale beds 1 ft. each near middle of unit	28.0	222.3
Chert, dense, white, partly oölitic	6.0	194.3
Covered interval, much dense, white chert float	15.0	188.3
Largely covered, small exposures of brownish white, dolocastic chert	9.0	173.3
Chert, massive, white, few sand grains	4.0	164.3
Dolomite, thick-bedded, coarsely crystalline; several thin sandy and shaly zones throughout the dolomite	54.0	160.3
Dolomite, cherty, weathers mealy; partly dolocastic	5.0	106.3
Dolomite, light to dark gray	21.0	101.3
Dolomite, dark gray; some dark shale and chert	4.0	80.3
Dolomite, light gray; thin white chert bed 9 ft. from top; many wavy, limonite-stained shale partings 16–20 ft. from top	46.0	76.3
Shale, grayish green	0.3	30.3
Dolomite, light gray; limonite-stained, wavy bedding surfaces and thin edgewise conglomerate 15 ft. from top of unit	30.0	50.0
CHEPULTEPEC DOLOMITE (contact indefinite)		
Chert, white; some greenish shale	10.0	566.0
Dolomite, light gray, slightly mottled	91.0	556.0
Chert, white	4.0	465.0
Dolomite, fine-grained, gray; bedded and nodular chert throughout unit; 1 ft. of white chert at base	83.0	461.0
Dolomite, dark and light gray, containing numerous dark bituminous shale partings	38.0	378.0
Dolomite, dark to light gray; numerous geodes; highly porous chert bed 1 ft. thick at top; several thin shale partings; *Lingula* brachiopod 23 ft. above base; ripple marks with black bituminous partings at base	86.0	340.0
Dolomite, gray, cherty; several sandy and shaly zones scattered throughout unit; ripple marks and sun cracks 32 ft. below top; cryptozoans, 4 in. in diameter, 26 ft. above base	134.0	254.0
Chert, oölitic, few sand grains at base	2.0	120.0
Dolomite, light to dark gray; thin oölitic chert beds 14 ft., 52 ft., and 60 ft. below top	118.0	118.0
COPPER RIDGE DOLOMITE		
Sandstone, dolomitic cement; thin shale and dolomite beds at top	3.5	1048.5
Dolomite, massive, finely crystalline; 1.5 ft. shaly zone 9 ft. below top; massive, coarse, siliceous oölite bed 1.5 ft. thick 35 ft. below top; 1 ft. cross-laminated sandstone; flat pebble conglomerate, oölitic matrix 0.1 ft. thick 60 ft. from top; 0.8 ft. dolomitic sandstone bed containing dolomite pebbles 80 ft. below top; shale beds, 0.1–0.3 ft. thick 8 ft. and 18 ft. above base	118.0	1045.0

TABLE I—(*continued*)

Description	*Thickness of Unit (Feet)*	*Thickness to Base of Formation (Feet)*
Dolomite, light gray, finely cyrstalline, cherty; 0.3 ft. of white, irregular, oölitic chert 5 ft. below top; thin laminations of sandy shale about 1 ft. thick 25 ft., 33 ft. and 40 ft. below top; 4 ft. of white oölitic chert and bedded black chert nodules 80 ft. from top; 0.2–0.6 ft. bed of black oölites, 88 ft. below top; cryptozoan 8 ft. above base; 0.2–0.3 ft. dark oölitic and conglomeratic chert at base	153.0	927.0
Dolomite, thick-bedded, dark gray, fine- to coarse-crystalline, gray, with many calcite veinlets	20.0	774.0
Dolomite, thick-bedded, light gray, fine- to coarse-crystalline, weathering white; contains many irregular, white, chert bands, some containing small oölites	18.0	754.0
Dolomite, medium- to thick-bedded, light and dark gray; thin-bedded shaly dolomite 7 ft. thick, 58 ft. below the top; distinct fetid odor of hydrocarbons 60–70 ft. below top	123.0	736.0
Covered interval	20.0	613.0
Dolomite, light gray, banded, weathering white; many small nodules and thin bands of chert; abundant wavy bituminous partings; fetid odor on fresh surface throughout most of unit; 1 ft. conglomeratic bed 6 ft. beneath top; 1 ft. bed of coarse oölites 94 ft. below top; 1 ft. bed of black oölitic and conglomeratic chert at irregular, possibly disconformable surface at base of unit	117.0	593.0
Shale, dolomitic, with a few thin chert beds	8.0	476.0
Dolomite, light and dark gray, banded	9.0	468.0
Chert, light and dark; abundant small cryptozoans	4.0	459.0
Dolomite, light to medium gray, granular, containing numerous calcite flecks; fetid odor	22.0	455.0
Dolomite, dark gray, fetid odor	100.0	433.0
Covered interval	25.0	333.0
Dolomite, black, coarsely crystalline	24.0	308.0
Dolomite, light gray, very finely crystalline	2.0	284.0
Dolomite, dark gray, very coarsely crystalline, weathering crumbly	5.0	282.0
Dolomite, dark gray, granular, fetid odor; small cryptozoan reef 18 ft. above base	80.0	277.0
Covered interval, some float fragments of dark chert and dolomite having fetid odor	85.0	197.0
Dolomite, dark gray, granular, fetid odor; shale and shaly dolomite 1 ft. thick at base	12.0	112.0
Dolomite, light and dark; sandstone zone 0.5 ft. thick 10 ft. below top; thin oölitic chert 12 ft. below top; 4 ft. of shaly dolomite at base	38.0	100.0
Dolomite, dark, little or no banding	52.0	62.0
Dolomite, dark, banded	10.0	10.0

differentiated. The limestones are in places variously mottled red, cream-gray, and pinkish.

Few persistent zones occur within the *Ceratopea* beds. Sandy zones observed at various horizons are not traceable more than short distances. A chert zone near the base and top of the zone may be found over much of northeast Tennessee. The lower chert is commonly bluish gray, weathering creamy white on the surface and containing several species of *Orospira*, *Hormotoma*, and *Calathium*. The upper chert occurs generally within a few feet of the top of the formation and consists

chiefly of a finely porous and cavernous, brownish chert, commonly fossiliferous, containing abundant specimens of the genera *Ceratopea*, *Orospira*, and *Eccyliopterus*. The fossils are apparently found in the chert and are rarly observed in the surrounding dolomite. This is generally the case throughout the Beekmantown. Much of the porosity of the upper chert is apparently due to dolocasts, where dolomite rhombs in the chert have dissolved, leaving their impressions. Dolocastic cherts are common throughout much of the Beekmantown and especially near the top. Siliceous oölites likewise occur commonly. As in lower oölites in the Beekmantown, they commonly show alternate layers of carbonate and silica, apparently representing alternating periods of penecontemporaneous deposition. In places the oölite grains show hollow centers, indicating the nuclei may have been dolomite or calcite which later dissolved leaving the silica layers. The *Ceratopea* zone has some fossils common to the Newala limestone of Alabama and southeast Tennessee; to the Jefferson City and Cotter formations of Missouri; to the Shakopee dolomite of the Upper Mississippi Valley; and to the Bellefont (and possibly Axemann) formation of central Pennsylvania. *Ceratopea* specimens are found in the Wells limestone in Wells Creek basin, northwest of the Central Basin of Tennessee. Also, limestones and dolomites in the Sequatchie Valley of south-central Tennessee contain *Ceratopea* near the top. Some deep wells of the Allegheny Plateau area of Tennessee have found dolomite at the top of the Beekmantown which Born[19] calls Zone C_2 and compares with the upper Beekmantown of east Tennessee and Sequatchie Valley in south Tennessee on the basis of lithologic characteristics and insoluble residues. The *Ceratopea* zone seems to underlie most of the plateau area of Tennessee and probably southeast Kentucky. Zone C_1 of Born's classification represents gray, tan, and brown sucrose dolomite found in several wells overlying Zone C_2 from which it is differentiated largely by the chert-free nature of the former. It is probable that this zone is not represented in most of the outcrop area of east Tennessee and Virginia. However, beds representing Zone C_1 probably occur near the Allegheny front in the Cumberland belt.[20] Here the sucrose dolomite and limestone of the Beekmantown appear transitional into the Middle Ordovician. In most other places in the valley area these upper beds were probably removed during the extensive post-Beekmantown erosion.

The *Ceratopea* beds were divided into the Forked Deer and Thorn Hill formations by Hall and Amick,[21] and Oder[22] applied Missouri nomenclature in Tennes-

[19] Kendall E. Born, "Lower Ordovician Sand Zones ('St. Peter') in Middle Tennessee," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 22 (1938), p. 1657.

[20] C. E. Prouty, "Lower Middle Ordovician of Southwest Virginia and Northeast Tennessee," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 30 (1946), p. 1147.

[21] G. M. Hall and H. C. Amick, "The Section on the West Side of Clinch Mountain, Tennessee," *Jour. Tennessee Acad. Sci.*, Vol. 9 (1934), p. 160.

[22] C. R. L. Oder, "Preliminary Subdivision of the Knox Dolomite in East Tennessee," *Jour. Geol.*, Vol. 42 (1934), pp. 483–88.

see, calling the lower part Jefferson City, and the upper part the Cotter-Powell beds. Cullison[23] did not consider the former classification to consist of mappable units, and thought the latter classification unsatisfactory in view of indefinite boundaries in the Missouri sections. He applied the informal name Post-Longview to these beds. Additional nomenclature,[24] the Kingsport and Mascot, has been referred to these beds, the former essentially equivalent to the Forked Deer or Jefferson City, the latter essentially equivalent to the Thorn Hill or Cotter-Powell beds. Application of Missouri nomenclature in this area without revision appears inadvisable.

Major disconformity.—With the exception of a few areas along the northwest belts, the Appalachian Valley of Virginia underwent considerable erosion after Beekmantown time. This erosion resulted in the complete removal of the upper Beekmantown from many parts of the area. Local relief of 200–300 feet is not uncommon and it is even greater in places in the southeast belts. In the northwest belts the erosion surface does not generally appear as rugged, but pronounced erosion is indicated in most places by the low undulating surface at the top of the dolomite and also by the presence of dolomite pebbles in the basal clastics of the overlying Middle Ordovician limestones. The magnitude of the hiatus may be considerably greater than that indicated by the erosion of the *Ceratopea* beds. The occurrence of the younger Beekmantown in the northwest outcrop belts and beneath the Cumberland Plateau (Zone C_1 of Born), and the occurrence in Wells Creek Basin, central Tennessee, of some beds probably younger than Zone C_1 would indicate that younger Beekmantown occurs on the west. In Arkansas and Missouri strata probably still younger are represented by the Powell, Smithville, and Black Rock formations. These beds are younger than Cotter, partial equivalent of the upper Beekmantown of the Valley area. The magnitude of the post-Beekmantown hiatus thus appears to increase eastward.

Chazy limestones.—The various units of the Middle Ordovician in this area have been described in detail in a recent publication.[25] The Chazy is represented by clastics derived from erosion of the Lower Ordovician dolomites. The clastics (Blackford formation) are widely distributed throughout most of the area, thinning along southeast belts into Tennessee where, in the local absence of the Blackford, higher Cliffield limestones overlie the Beekmantown dolomites. The Lincolnshire limestone thickens from Virginia into Tennessee by addition at the base, resembling in appearance the more shaly Lenoir limestone facies of Tennessee, a partial equivalent of the Lincolnshire. The overlying Thompson Valley clastic limestone occurs throughout the southeast belts in Virginia and Tennessee,

[23] J. S. Gullison, "The Geology of the Norris Reservoir Region," *Tennessee Valley Authority, Geology Division Manuscript* (1937), p. 72.

[24] John Rodgers and D. F. Kent, "Section at Lee Valley, Hawkins County, Tennessee." *Manuscript* (1944).
John Rodgers, "Geologic Map of Copper Ridge District, Hancock and Grainger Counties, Tennessee," *U. S. Geol. Survey Strategic Minerals Investigations Prelim. Map* (1944).

[25] C. E. Prouty, *op. cit.*, pp. 1140–91.

being partly equivalent of the commercial "Holston" marble of the Knoxville, Tennessee, area (Farragut limestone). The upper Cliffield (Ward Cove and Peery formations) thin from Virginia into Tennessee, disappearing entirely in southwest Virginia and northeast Tennessee.

The entire Cliffield group thins northwestward largely by convergence, disappearing entirely in most places along the belts nearest the Cumberland-Allegheny escarpment where Black River limestones overlap the Beekmantown. In Tennessee, only a part of the Chazy limestones occurs northwest of Clinch Mountain (Fig. 5), indicating the greater effectiveness of a barrier in Tennessee than in Virginia. This barrier, coinciding closely with Clinch Mountain and approximately outlined on the southeast by the Saltville thrust, is here referred to as the Tazewell axis named for Tazewell County, Virginia.

Black River limestones.—The base of the Black River is thought to include units probably as low as the Thompson Valley limestone. The Benbolt limestone appears equivalent to the basal type Black River in New York. The Thompson Valley, Ward Cove, and Peery thus represent older Black River than present in New York. The Black River thins largely by convergence, from nearly 1,000 feet in southwest Virginia to less than 400 feet in southeast West Virginia. This thinning continues into Pennsylvania and New York, pre-Pamelia units cutting out entirely before reaching northwestern New York. From Virginia into Tennessee the Black River thickens in general and becomes more clastic, the most pronounced change being observed in the grading of the Benbolt-Gratton-Wardell facies into the Sevier shale facies. The Sevier is best developed southeast of Clinch Mountain (and the Tazewell axis) and represents a more typically geosynclinal deposit. This southwestward coarsening and thickening along the various belts northwest of Clinch Mountain indicate that the geosynclinal facies extends farther northwest in Tennessee than in Virginia, relative to the structural belts. The structural belts in northeast Tennessee do not follow the gradational isoliths but apparently cut across them at a low angle.

The Tazewell axis was an effective barrier throughout much of the Black River (Fig. 5), the interval thinning from more than 4,400 feet in the Bays Mountain area southeast of Knoxville, Tennessee, to less than 800 feet northwest of the axis near the Cumberland escarpment. The Farragut limestone ("Holston marble") thins northwestward and disappears northwest of the arch. The Tellico sandstone shows offlap relationship to the Farragut, thinning out on the southeast flank of the axis. The lower Sevier shaly limestone overlaps the Tellico toward the arch. The middle Sevier, characterized by numerous small *Receptaculites* extends farther northwestward and crosses the arch, but thins out directly northwest of the axis. The upper Sevier, identified by numerous large *Receptaculites*, and the overlying Bowen formation show offlap relationships with the lower Sevier, possibly due to pre-Witten erosion. In any event the Witten ("Lowville") limestone shows a disconformable basal relationship, overlapping northwestward the Bowen, upper and middle Sevier, Lenoir limestone (Chazy), and finally the

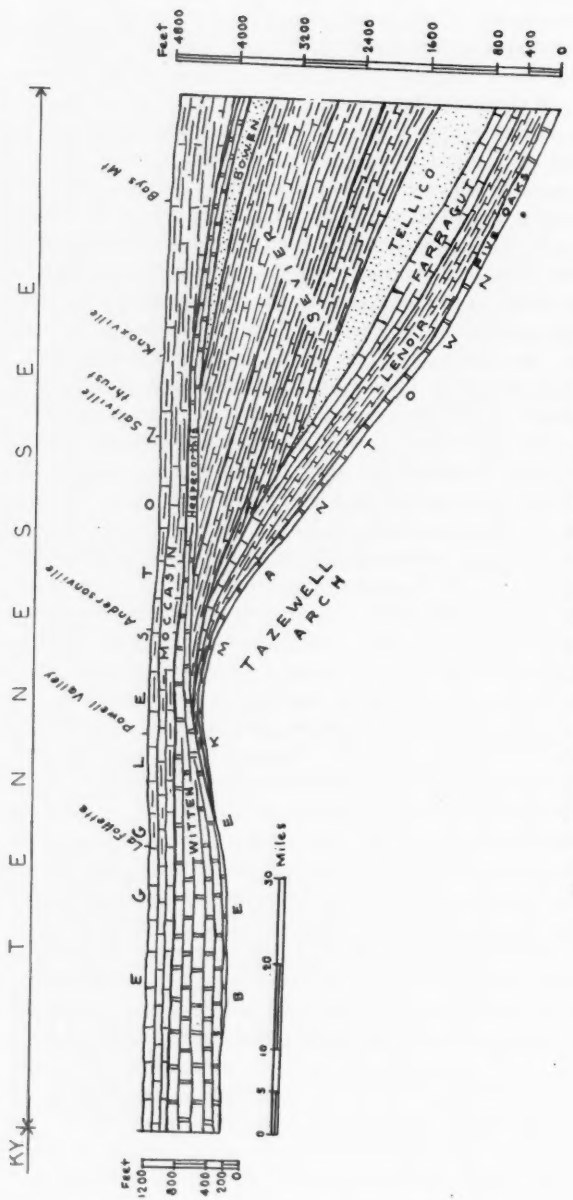

FIG. 5.—Restored section across Tazewell arch in northeast Tennessee.

Beekmantown near the Cumberland front. Though the entire Chazy and most of the Black River are cut out along this stratigraphic break, angular relationships are nowhere locally observable in the field.

The Witten limestone, uppermost Black River, thickens northwest of the arch, apparently reflecting the depressed foreland trough. This trough, as well as the Tazewell axis appear to be more pronounced in northeast Tennessee than in Virginia.

Trenton limestones.—The Moccasin claystone, representing the basal Trenton series, is distributed throughout the area. Southeast of Clinch Mountain the formation, typically red calcareous claystone, becomes coarser toward its southeastward source. Northwest of Clinch Mountain sandy zones disappear, the claystone containing a few thin dove-colored fine-grained argillaceous limestones. The typical red color of the Moccasin changes partly to buff along the northwest belts in Tennessee and in such cases the Moccasin is not readily differentiated from the overlying Eggleston. The Moccasin thins northeastward from Tennessee into Virginia in belts both allochthonous and autochthonous to the Saltville thrust. In the latter area the typical red claystone disappears as the Moccasin facies passes into the less clastic Nealmont facies in the northwest belts of Virginia and southeast belts of West Virginia (Fig. 6).

The overlying Eggleston consists of buff and gray shaly limestone and is distributed throughout the northwest belts, thinning northeastward from 150 feet near the Tennessee-Virginia line to less than 50 feet near the West Virginia line. Two thick metabentonite beds persist throughout the area, extending into the Tyrone of Kentucky[26] and the Nealmont of Pennsylvania.[27] The grayish buff shale and claystone is not readily differentiated from the overlying Martinsburg formation.

The Martinsburg consists of alternating shales and limestones of Trenton, Eden, and Maysville age. The base might well be placed beneath the first occurrence of *Dalmanella rogata* and *Sowerbyella curdsvillensis* (Curdsville equivalents). These forms are commonly present in a thin coquinal limestone directly above the upper thick bentonite of the Eggleston. In general, the basal Trenton limestones are more coarsely crystalline and darker than those of the Eggleston and Witten formations. Above the Curdsville equivalents the Trenton contains fossils in the lower part similar to those described by Bassler[28] from the Hermitage of the Central basin of Tennessee; middle Trenton limestones contain equivalents of the Cannon formation; and the upper Trenton contains forms similar to the Catheys formation. The top of the Trenton is not readily defined in the southeast belts where the overlying Eden equivalents are alternating buff to gray shales and

[26] G. G. Huffman, "Middle Ordovician Correlations from Lee County, Virginia, to Central Kentucky," *Bull. Geol. Soc. Amer.*, Vol. 53 (1945), pp. 145–74.

[27] G. M. Kay, "Middle Ordovician of Central Pennsylvania," *Jour. Geol.* (1944), p. 109.

[28] R. S. Bassler, "The Stratigraphy of the Central Basin of Tennessee," *Tennessee Div. Geol. Bull. 38* (1932). 268 pp.

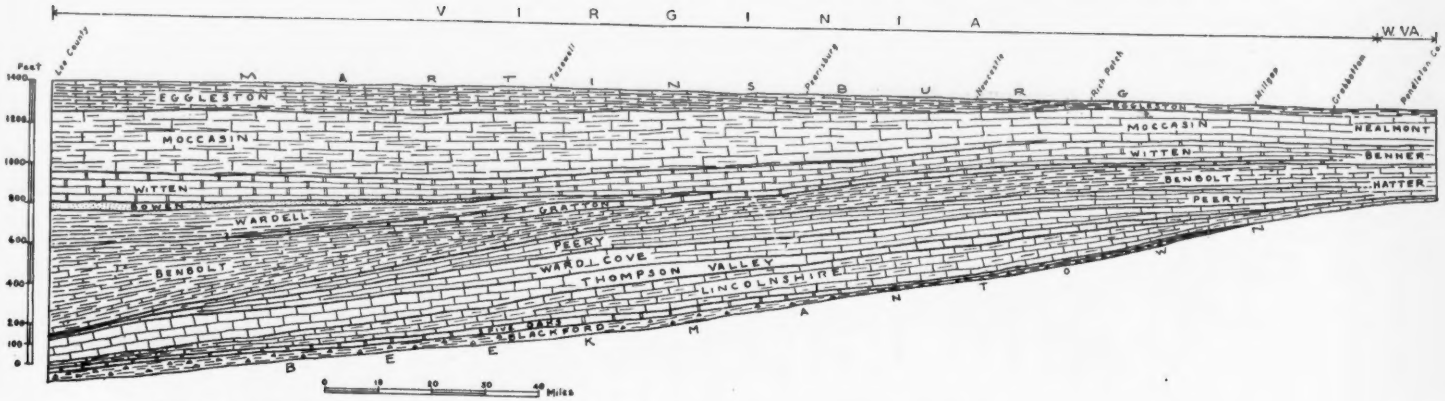

FIG. 6.—Restored section of Curdsville (Trenton)-Beekmantown interval from southwest Virginia to Pendleton County, West Virginia.

blue limestones much like those of the Trenton. In these belts subdivision of the Trenton, Eden, and Maysville is impractical lithologically and the three formations are generally mapped as the Martinsburg formation. In the extreme northwest belts of Tennessee and Virginia, the Trenton may be separated lithologically from the Eden and Maysville, the latter two being more shaly. The Eden and Maysville are then mapped as the Reedsville formation. The upper part of the Reedsville (upper Maysville) commonly consists of reddish calcareous claystone, especially in the southeast belts, and is not readily differentiated in such instances from the overlying Juniata formation. The upper Reedsville contact might best be drawn optionally above the last appearance of *Orthorhyncula linneyi* which occurs near the top of the Martinsburg and Reedsville throughout Tennessee and Virginia. In general, the Reedsville in the northwest belts is buffish gray and is thereby readily differentiated from the red Juniata or the Sequatchie formation, the calcareous marine equivalent of the Juniata occurring mostly northwest of Powell Valley in Tennessee and Virginia. The upper Reedsville is conformable with the Juniata in all places observed and is in most places gradational. Where the Juniata grades laterally into the Sequatchie limestone, the upper Reedsville becomes increasingly calcareous. As the Juniata is in turn gradational into the overlying Silurian (Tuscarora-Clinch) sandstone, it appears that this area was little affected by the Taconic disturbance and there are few structural criteria for definitely placing the systemic boundary.

The thickness of the Martinsburg is not readily determined because of the highly folded nature of the incompetent thin shales and limestones. Fairly close measurements would indicate an average thickness of 1,000–1,300 feet. The Trenton equivalents vary from 300 to 600 feet and the combined Eden and Maysville equivalents are commonly 400–675 feet thick.

PALEOGEOGRAPHY AND GEOLOGIC HISTORY

The area here discussed lies chiefly northwest of Clinch Mountain and its northeastward extension and also northwest of a structural axis which is considered to be a possible southwestward continuation of the Adirondack axis. This axis (Tazewell axis) is outlined closely on the southeast side by the Saltville thrust, and possibly had some part in determining the position of that fault. Clinch Mountain follows the line of the axis fairly closely in Tennessee and Virginia. The structure extends at least from northern Virginia to east-central Tennessee and may coincide in part with the Rome barrier of Ulrich.[29]

The axis was effective at times during the Cambrian and Ordovician in dividing the Appalachian trough into two parts, the area on the southeast being more typically geosynclinal with thick, well developed sections; the area on the northwest being in the Allegheny synclinorium and containing thinner, and generally less clastic, units.

[29] E. O. Ulrich, "Revision of the Paleozoic System," *Bull. Geol. Soc. America*, Vol. 22 (1911), p. 293.

During the Lower Cambrian the geosyncline filled with clastics (Chilhowie series) largely derived from the high Appalachian landmass on the southeast. Conditions were more stable and the landmass lower in later Lower Cambrian as indicated by the Shady dolomite, followed by thick shales of the Rome formation. Middle Cambrian sediments grade from largely clastic along the northwest side of the area to non-clastic on the southeast (Fig. 2), suggesting a general northwestward to westward source. Deposition of carbonates followed during the Upper Cambrian, dolomite (Copper Ridge) forming in the synclinorium and limestone (Conococheague) on the southeast. The gradation isolith coincides fairly closely with a line parallel with the Saltville thrust (Fig. 3). This line appears to connect closely with the southwestern extension of the Adirondack axis, of structural importance in Pennsylvania and New York during the Middle Ordovician. The change from dolomite to limestone occurs so sharply along this line that a partial barrier of some kind is inferred during Upper Cambrian time. It is probable that the barrier represents the beginning of a fairly broad structurally high area which developed into the more sharply defined Tazewell axis (arch) of the Middle Ordovician (Fig. 5).

The origin of the dolomite appears to have some relationship with the barrier. It is here suggested that the area northwest of the barrier was sufficiently restricted from the circulating waters of the geosyncline that a higher degree of concentration of salts was possible. Though calcium carbonate was probably deposited at first, replacement of the limestone took place before consolidation. The dolomite was primary in the sense that the replacement was penecontemporaneous with deposition. The apparently low porosity of the dolomite tends to preclude an epigenetic origin for the dolomite though the theoretical shrinkage of dolomitization of consolidated limestone may not necessarily occur in all cases. The absence of fossils in the dolomite, but their presence in chert within the dolomite, indicates that penecontemporaneous dolomitization modified the sediments sufficiently to obliterate the organisms but did not develope porosity in the unconsolidated lime. This calls for an earlier consolidation of the chert in order to explain the preservation of the contained organisms during penecontemporaneous dolomitization.

The sandstone beds of the upper Copper Ridge dolomite were, according to textural analyses, derived from the west or northwest—possibly the same source that supplied the Middle Cambrian shales. The conditions that brought about the sedimentation of the water-transported sands, occurring within several hundred feet of dolomite with little or no clay present anywhere at this horizon, present an interesting problem. In any event, rejuvenation of the source probably occurred several times in Upper Cambrian time. This source may have been the Cincinnati arch, but this suggests an earlier history for this structure than thus far acknowledged, movement of Black River age having been recognized by Wilson,[30]

[30] C. W. Wilson, "The Pre-Chattanooga Development of the Nashville Dome," *Jour. Geol.*, Vol. 43 (1935), pp. 449–81.

and Trenton movement considered by McFarlan.[31] Subsequent work by McFarlan tends to alter original observations on the Trenton history of the arch.[32] Inasmuch as there are no exposures of the Upper Cambrian along the arch in Kentucky and only limited structural control from deep wells on which to base conclusions, it is likely that any evidence for an early history for the arch would not be recognized. It is possible, of course, that some area farther northwest of the arch may have been the source, as possibly the pre-Cambrian ridges described by Cohee in Michigan.[33] The Cincinnati arch area offers a closer and possibly a more likely source in view of similar occurrences of sand zones in the equivalent Gatesburg of Pennsylvania. Thus, a somewhat linear source sub-parallel with the axis of the synclinorium is indicated rather than a point source at a much greater distance. The sand zones of the Gatesburg occur throughout the formation in definite cyclic arrangement indicating a more unstable part of the synclinorium in which shorelines shifted more frequently over the broad, very shallow trough. This cyclic occurrence of the sandstones is not as noticeable in the Copper Ridge.

Carbonate deposition continued into the Lower Ordovician. As in the Upper Cambrian dolomite occurs northwest of the Tazewell axis and limestone occurs southeast, the gradation isolith coinciding closely with that structure (Fig. 4). The environmental conditions were apparently similar to those of the Copper Ridge. The lower Beekmantown (Chepultepec), however, disappears probably by convergence from Tennessee into Virginia along the northwest belts. Chepultepec equivalents (Stonehenge) reappear, however, in central Pennsylvania, indicating that either the Chepultepec was removed by erosion in Virginia before late Beekmantown time or that deposition did not occur. No physical evidence for such erosion is observable in Virginia and the latter appears more feasible, especially in view of the extremely shallow nature of the southeast margin of the synclinorium and the slight movement required to raise wide areas of the trough.

The basal Chazy deposits consist of reworked Beekmantown, indicating a broad general emergence and period of erosion throughout most of Tennessee and Virginia. Considerable local relief is present in many places. The structural barrier which was effective in separating the dolomite and limestone facies of the Upper Cambrian and Lower Ordovician showed upward movement in the Chazy, some units thinning by convergence and overlap toward the structure (Tazewell arch, Fig. 5). The Chazy rocks become more clastic southeastward indicating a shift in the source direction and a rejuvenation of the landmass on the southeast which had apparently been low since the Lower Cambrian.

The Tazewell arch continued as an effective barrier into Black River time,

[31] A. C. McFarlan, "Stratigraphic Relationships of Lexington, Perryville, and Cynthiana (Trenton) Rocks of Central Kentucky," *Bull. Geol. Soc. America*, Vol. 49 (1938), pp. 989–96.

[32] *Idem*, "Trenton and Pre-Trenton of Kentucky," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 32, No. 8 (August, 1948), pp. 1627–1646.

[33] G. V. Cohee, "Stratigraphy of Lower Ordovician and Cambrian Rocks in the Michigan Basin," *U. S. Geol. Survey Prelim. Chart 9*, Oil and Gas Investig. Ser.

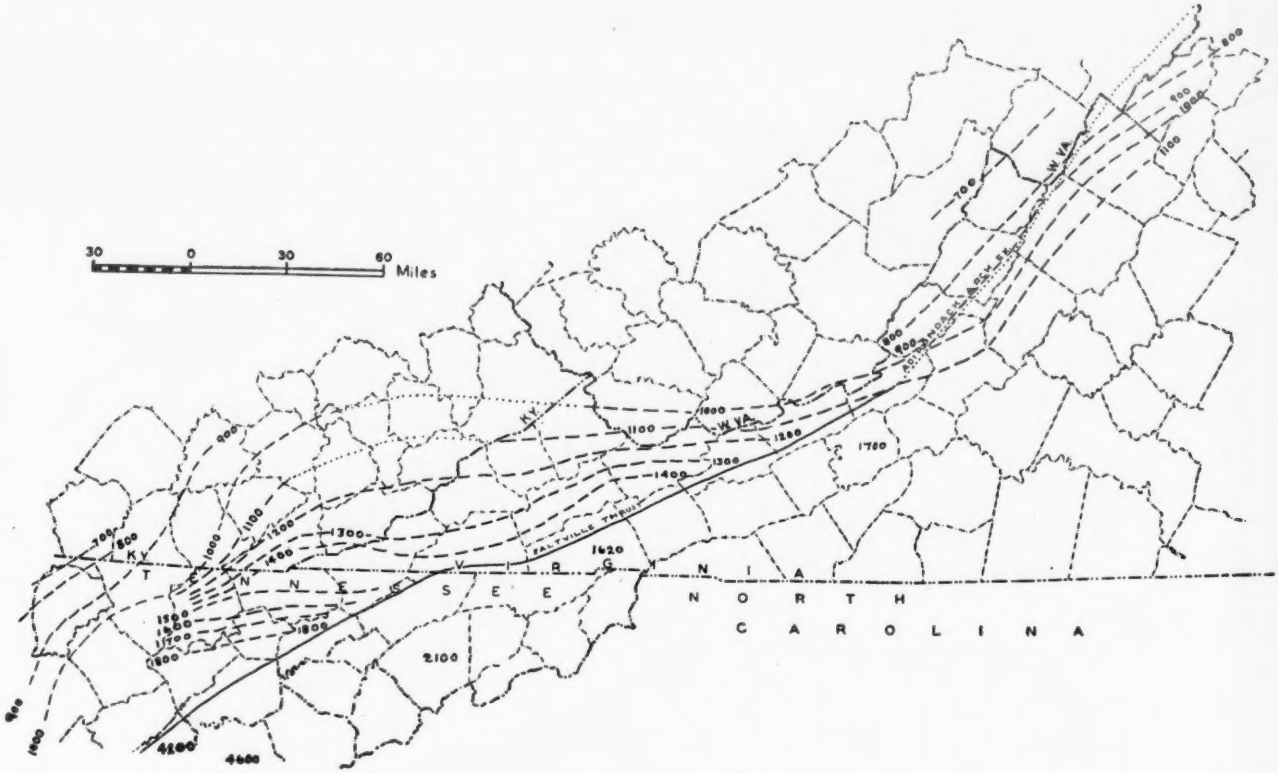

FIG. 7.—Isopachous map of Curdsville (Trenton)-Beekmantown interval.

the Athens and the northwest equivalent, the Ward Cove, showing sharp faunal and lithic differences on opposite sides of the structure in Virginia.[34] In Tennessee only a small amount of the Black River sediments passed the arch, extending only a short distance northwest. During the uppermost Black River, the trough northwest of the arch lowered appreciably, receiving thick limestones (Witten). It is as though the Tazewell arch was more effective in separating two well defined troughs in Tennessee during this time than at any other time.

During the lower Trenton the landmass showed renewed activity, thick clay deposits (Moccasin) filling the geosyncline and spreading northwestward into the synclinorium. The red claystone grades into blue argillaceous limestone before the Cumberland front is reached. The higher Trenton consists of alternating shales and limestone in the geosyncline, becoming predominantly limestone in the northwest belts. Alternating shales and limestones were deposited in the geosyncline and synclinorium during Eden and Maysville time, indicating continued fluctuations in the relief of the source on the southeast.

The Tazewell arch was not as effective a facies barrier during Martinsburg time in Tennessee and Virginia as was its likely northeastward extension, the Adirondack axis, in Pennsylvania and New York. Apparently the Tazewell arch and the Adirondack arch did not show simultaneous or at least equal degrees of movement along the structure. It is highly probable that the same is true of the Cincinnati arch, as evidenced in earlier discussions.

The isopachous map for the Chazy, Black River, and lower Trenton (Fig. 7) shows the thickness of the rocks to increase rapidly toward the southeast, especially in Tennessee. The isopachs run fairly close to the structural belts in Virginia but diverge appreciably toward the west in Tennessee. The Saltville thrust apparently followed the Tazewell axis much more closely than the isopachs. It appears that the Tazewell axis may have largely controlled the position of the Saltville fault. Isoliths likewise closely parallel the structural belts in Virginia but cut westward across the outcrop belts in Tennessee, following closely the isopachs. Apparently the geosynclinal facies extended farther northwest in Tennessee than in Virginia. This may be further demonstrated by the general increase in clastic sediments from Virginia to Tennessee along the various belts.[35] It is apparent that the greater northwest extent of the geosynclinal facies in Tennessee can be explained only in part by the greater northwestward movement of the thrusts in that area.

STRUCTURE

The major structural elements of this area have been previously described by the writer.[36] The area lies in the highly folded and faulted Valley and Ridge prov-

[34] C. E. Prouty, "Lower Middle Ordovician of Southwest Virginia and Northeast Tennessee," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 30 (1946), p. 1190.

[35] C. E. Prouty, *op. cit.*, p. 1189.

[36] C. E. Prouty, *op. cit.*, pp. 1141–44.

ince. The southeast part of the area is bounded by the Saltville thrust, showing great horizontal displacement in Tennessee, and increasing toward the southwest. In Virginia the thrust diminishes in magnitude, disappearing entirely along Sinking Creek Valley in Craig County. Between the Saltville thrust and the Allegheny front the area is faulted into blocks of shingle-like arrangement. The horizontal displacement of the thrusts, probably less than that of the Saltville block in most places, is about equal in each of the smaller fault blocks on the northwest. The thick soft shales of the Rome formation (Lower Cambrian) are thought to have been the loci of thrusting in most faults. Though the Rome is repeated several times, the base is nowhere observed in the northwest belts. It is probable that the higher soft shales served as lubricating planes for the thrusting. Northeastward in Virginia younger beds have in general been brought up along the thrusts indicating the decrease in stratigraphic throw in that direction. The greater horizontal displacement of the thrusts in the extreme southwest corner of Virginia and northeast Tennessee may be due at least in part to the presence of the Cumberland overthrust block.[37] The Pine Mountain fault, which crops out northwest of the Cumberland Allegheny front, ends in tear faults on the northeast in Dickenson and Buchanan counties, Virginia (Russell Fork fault) and on the southwest in Campbell County, Tennessee (Jacksboro fault). The Cumberland thrust block has moved several miles northwestward,[38] causing horizontal shear along the tear faults. The faults on the southeast (Walden Valley, St. Paul, Copper Creek) somewhat reflect the salient caused by the northwestward movement of the Cumberland overthrust block.

Current interest in the oil possibilities of the Cumberland overthrust block has created considerable interest in local structures. The chief elements of the structure are indicated to be a broad anticline (Powell Valley or Dividing Ridge) developed in the overthrust sheet.[39] The anticline extends from a point near Little Stone Gap, Wise County, Virginia, to a point east of Jacksboro, Tennessee. The fold is apparently not simple but contains several smaller flexures which are sub-parallel with the main fold. In the Tennessee part of the Powell Valley anticline there is some evidence of cross-folds in the structure.[40] This is based on the

[37] C. K. Wentworth, "Russell Fork Fault of Southwest Virginia," *Jour. Geol.*, Vol. 29 (1921), pp. 351–69.
John L. Rich, "Mechanics of Low-Angle Overthrust Faulting as Illustrated by Cumberland Thrust Block, Virginia, Kentucky, and Tennessee," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18 (1934), pp. 1584–96.

[38] C. K. Wentworth, *op. cit.*, pp. 351–69.
Charles Butts, "Fensters in the Cumberland Overthrust Block," *Virginia Geol. Survey Bull. 28* (1927), p. 8.

[39] Charles Butts, *op. cit.*, p. 5.
R. L. Miller and J. O. Fuller, "Geology of the Rose Hill Oil Field, Lee County, Virginia," *U. S. Geol. Survey Prelim. Map 20*, Oil and Gas Investig. Ser (1944).

[40] J. S. Cullison, "The Geology of the Norris Reservoir Region of Tennessee," *Tennessee Valley Authority, Geological Division Manuscript* (1937).

east-west alignment of inliers of the Conasauga formation, occurring in the Clouds, Ausmus, and Well Spring quadrangles. Joints and small faults in the inliers also show east-west orientation, and cross the general structure of the Powell Valley anticline at angles as much as 45°. The inliers are erosional in origin and occur entirely within the overthrust sheet. If there alignment does represent a cross-fold, it is likely that it reflects east-west folds in the underlying block. Further evidence that the structure of the overlying block might not conform with that of the lower block is based on the difficulties found in anticipating various horizons within the underlying block in drilling operations. This might indicate the presence of folds or faults in the lower block which developed prior to or during the overthrusting of the Cumberland block, a factor of considerable importance in oil investigations.

Minor structures in the general area include both tensional and compressional joints. The tensional joints are parallel with the general strike of the rocks (strike joints) and therefore strike from approximately N. 45° E. to approximately due east. Strike joints may be observed in all of the rock units. Most of the joints developed in calcareous rocks show considerable enlargement because of solution. The joints are generally approximately normal to the bedding planes. Compressive (shear) joints occur in most of the formations but are conspicuously absent from some units. In such places, overlying and underlying units may be highly jointed. In general, the compressive joints are more numerous in shales and argillaceous limestones and dolomites than in massive limestones or sandstones. The compressive joints cross the strike of the rock at angles depending largely on the type of rock. In accord with theoretical expectations, the compressive (shear) joints which have developed in highly competent sandstones and limestones form in two sets joining at acute angles. In shales and highly argillaceous limestones, the angle is more obtuse. A line bisecting the angle between the two sets of compressive joints is nearly parallel with the apparent direction of stress.

Core drilling at several of the Tennessee Valley Authority dams has indicated the presence of both tension and compression joints to depths several hundred feet below the surface. Many of the joints, especially strike joints, have been opened by solution to depths almost 300 feet beneath the surface and nearly that depth below the water table.

OIL AND GAS POSSIBILITIES

The area here discussed forms a part of the highly folded and faulted Valley and Ridge province and therefore would not be generally considered a likely region for oil and gas accumulation in commercial quantities. Recent developments in the Cumberland overthrust block, however, have produced the first oil in Virginia. The area of current interest is near Rose Hill, Lee County, where drilling to date has been in fensters occurring within the overthrust block. The area has been studied recently and described by the United States Geological Survey.[41]

[41] R. L. Miller and J. O. Fuller, *op. cit.* (1944).

Production has been chiefly from the Trenton, though some oil has been obtained from the Eggleston formation and Witten ("Lowville") limestone and a showing of oil was obtained from the upper Beekmantown dolomite. Initial production in a few wells reached approximately 200 barrels a day but is reported to have dropped appreciably in a few weeks. The oil is high grade, of approximately 45° gravity, and accompanied by little or no gas. Little is known about the rock porosity. The producing beds are separated by several different beds in the Trenton. The similarity of the oil from widely separated beds, the drop of initial production, the lack of gas, and the general absence of any particularly permeable beds strongly suggest fracture porosity. Since all production has so far been from the underlying block, fracture porosity might be questioned as it is conceivable that the weight of the overlying Cumberland thrust sheet might largely seal any fractures developed prior to the thrusting. However, this is conjectural and the evidence at hand would tend to deny it.

Insufficient drilling has taken place to date satisfactorily to outline the pool. Some consider the entire Cumberland overthrust block, extending approximately 125 miles southwest along the Valley, and 30 miles northwest across the Valley, as a potential reservoir. There has been no drilling southwest in the Tennessee part of the structure. The Powell Valley anticline, along which most of the drilling has taken place, occurs along most of the length of the overthrust block. Southwestward into Tennessee, however, the Pine Mountain thrust has raised older strata along the thrust sheet. Also younger strata cover the anticline in places in Tennessee. Thus, the overlying block becomes appreciably thicker southwestward and would greatly increase the depth of drilling necessary to contact the underlying block. Drilling at present is in fensters in the overlying block, near the northeast end of the Powell Mountain anticline. The possibilities for future exploration would logically be southwest along the structure. However, a few wells drilled in that direction have encountered difficulty in finding some beds at anticipated elevations. It appears that the structure of the underlying block does not conform with that of the overlying block, and as suggested, this might be due to cross-folds or faulting developed in the area now comprising the lower block, before or during the overthrusting of the Cumberland block. Though increasing difficulty might be encountered southwest along the structure, exploration has not yet reached the stage where the worthiness of such a venture can be discounted.

There are probably no other structures in the area that offer the oil possibilities of the Cumberland overthrust sheet. The carbon ratio of coals along the Allegheny front increases northeast of the Cumberland overthrust block, reaching the theoretical limit for the occurrence of oil (60 per cent fixed carbon) in Lee County, Virginia.[42] Though too much emphasis should perhaps not be placed on this critical ratio, it is interesting to note that oil has not been found farther

[42] W. M. McGill, "Prospecting for Natural Gas and Petroleum in Virginia," *Virginia Geol. Survey Bull. 46-B* (1936), Pl. 4.

northeast where the ratio is higher (62.5 per cent). On the basis of carbon ratios, oil possibilities might be expected to improve southwestward along the Cumberland overthrust block into Tennessee, though previously mentioned factors should be considered. The Sequatchie Valley southwest of and along the approximate strike of the Cumberland overthrust block offers interesting possibilities, and especially any sub-parallel structures beneath the plateau on the northwest which may have been formed complementary to the northwestward movement that formed the Sequatchie anticline.

The Early Grove gas field, in Scott and Washington counties, Virginia, produces from sands in the Mississippian which show a porosity of 1.6 per cent and a permeability of about .00285 millidarcy. The composition of the gas, 98.2 per cent methane is approximately proportional to the fixed-carbon ratio (60) of Lee County coals.[43] Though this area appears less disturbed than most structures of the valley, the permeability in the Early Grove field approaches the minimum for commercial gas accumulation. Another belt of comparatively little deformation is the Devonian belt trending through southeast Bath and northwest Augusta and Rockingham counties, northwest Virginia, continuing into Hardy County, West Virginia. Gas has been derived from the Devonian near Bergton, Rockingham County, along this belt.

The possibilities of deeper oil and gas of Ordovician age in such areas have not been thoroughly explored. The Ordovician formations producing oil in the Cumberland overthrust block are widespread throughout the area. The showing of oil in the Beekmantown dolomites is of interest because of similar findings in Clay County, Kentucky.[44] The Upper Cambrian (Copper Ridge) has lithologic characteristics similar to the Lower Ordovician Beekmantown dolomite and though not generally considered as a potential source of oil, it is petroliferous throughout much of its thickness, yielding the characteristic fetid odor on fresh fracture. It is questionable whether the oil from the upper Beekmantown of Virginia and Kentucky was derived from the dolomite or the Ordovician limestones. The most porous layers of the dolomite are probably the well developed sand zones at the contact of the Beekmantown and Upper Cambrian. Few wells in the adjoining plateau area of Kentucky have penetrated these sands, only five having been drilled more than 1,000 feet into the dolomites. As the best results to date have been in the upper 150 feet of the dolomite where no sandy zones or very thin sandy zones are present, it may well be that fracturing determines the rock porosity, and local structure may be far more important than stratigraphy. However, the deeper Cambro-Ordovician sands have not been penetrated sufficiently to determine their potentialities. In view of the northwestward to westward source of these sands, they should increase in grain size and thickness under the

[43] Paul Averitt, "The Early Grove Gas Field, Scott and Washington Counties, Virginia," *Virginia Geol. Survey Bull. 56* (1941), p. 38.

[44] C. D. Hunter, "Kentucky Subsurface," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 32, No. 8 (August, 1948), pp. 1647–57.

plateau in Kentucky and Tennessee, a factor that might increase their potentialities as producers in that direction. The dolomites of the Beekmantown and Copper Ridge appear to be relatively non-porous compared with some dolomites, possibly reflecting a penecontemporaneous dolomitization prior to consolidation.

The Chazy limestones converge northwestward and in Tennessee are overlapped in that direction by Black River limestones, extending into Kentucky beneath the plateau. The Black River limestones become increasingly calcareous toward the northwest and are largely calcilutites along the Allegheny front, excepting for the upper argillaceous limestone equivalents of the Moccasin claystone facies. These beds indicate increasing carbonate content northwestward and should be largely limestone under the Kentucky and Tennessee plateau area. Though no particularly porous zones are observed along the northwest outcrop belts, the "Lowville" (Witten) produces some oil in the Rose Hill oil field. The Eggleston formation, likewise a small producer in the Rose Hill area, probably has the highest clay content of any of the Ordovician formations of the northwest belts with the possible exception of the Reedsville shale. Some beds are essentially claystones which would hinder vertical migration, unless fractured. The Trenton limestone, so far the best producer in Lee County, Virginia, is fairly pure, showing few if any potentially porous zones, with the possible exception of the coquinal beds.

The similarity of the oil in the Beekmantown, Eggleston, Witten, and Trenton in the Cumberland overthrust block area indicates a common source. As these zones are separated by several hundred feet of limestone, fracture porosity might most logically be inferred. Other factors tending to support this inference are the general absence of gas at all horizons and the reported appreciable drop of initial production. The apparent absence of suitable porous zones within the Trenton and sub-Trenton limestones indicates that fracture porosity should be strongly considered in future drilling operations in this area. In view of recent developments in southwest Virginia more wells may be drilled along the Allegheny front in Virginia and Tennessee, especially along the Cumberland overthrust block.

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TRENTON AND PRE-TRENTON OF KENTUCKY[1]

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Lexington, Kentucky, and New Orleans, Louisiana

ABSTRACT

Outcropping rocks range as low as the Stones River and include the High Bridge, Lexington, and Cynthiana beds. Their general character, significant fossils, and stratigraphic relationships are outlined. Two wells have penetrated the Cambrian, one probably the pre-Cambrian. Contributions by several workers have modified hitherto accepted stratigraphic alignments.

1. The upper Camp Nelson has been referred to the Lowville, and the Tyrone, and probably the Oregon along with it, to the Trenton.

2. The Perryville is shown to be a facies of the upper Benson. The so-called Perryville of Franklin and Woodford counties, renamed the Devil's Hollow division of the upper Lexington, is regarded as a facies of the upper Woodburn and probably also the lowermost Cynthiana.

3. The Sulfur Well member (pre-Greendale) of the lower Cynthiana in the southern and southwestern Bluegrass has been shown to be an overlapping facies of the late Lexington. Such a relationship also exists on the east.

4. The Lexington-Cynthiana-Eden is probably a conformable succession. Previously recognized mid-Ordovician structures, based on unconformable overlap, are abandoned as the overlap is shown to be one of facies.

The Ordovician rocks crop out along the axis of the Cincinnati arch in the central Bluegrass region and in the Cumberland River region of southern Kentucky. They are also exposed just east of Cumberland Mountain in Virginia and Tennessee on the edge of the Appalachians. With this latter exception, the mid-Ordovician is confined to the central region where the outcrop pattern is controlled by the Jessamine dome, a dome structure along the axis of the Cincinnati arch. The oldest beds exposed are those of the Camp Nelson formation in the Kentucky River Gorge at Camp Nelson in southern Jessamine County. The structure, however, rises for a half dozen miles southward to the vicinity of Burdett Knob in Garrard County where it is crossed by the Kentucky River fault. This fault system cutting the arch high on the structure abruptly terminates pre-Cincinnatian outcrops on the south and southeast, giving in effect a truncated half-dome.

North and northwest, the pre-Cincinnatian crops out extensively on the upthrown side of the fault, gradually sinking below drainage on the north along the Kentucky and Licking rivers in Henry and Harrison counties, and on the west in the valley of the Salt River in Mercer and Anderson counties. In this central region, the rocks of the Lexington limestone have given rise to the fertile Inner Bluegrass and those of the High Bridge series have yielded the rugged scenery of the Kentucky River Gorge.

The pre-Cincinnatian comprises three divisions in ascending order: the High Bridge limestone, the Lexington limestone, and the Cynthiana formation.

[1] Manuscript received, February 28, 1948.

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HIGH BRIDGE LIMESTONE

The High Bridge series consists of massive, cliff-forming limestone formerly referred to the Stones River and Lowville but more recently to the Lowville-Trenton. Three formations are recognized.

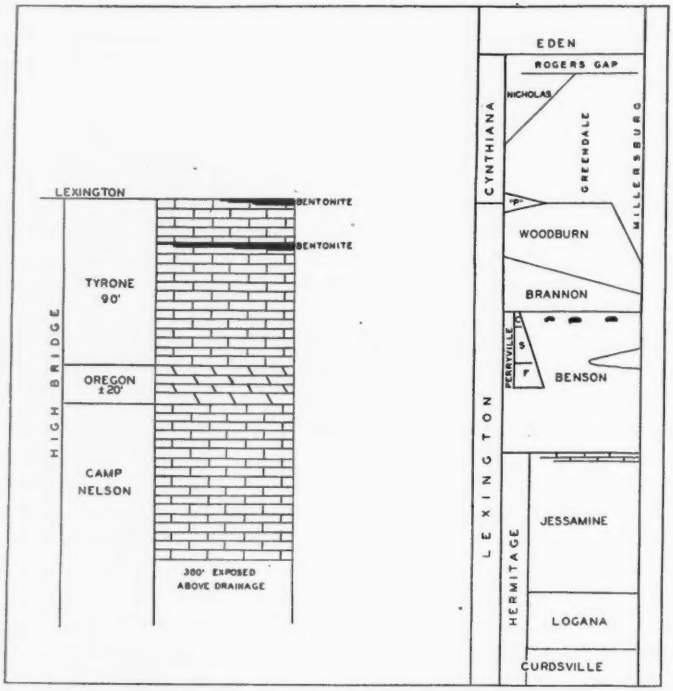

FIG. 1.—Generalized section of pre-Cincinnatian rocks of central Kentucky.

Camp Nelson limestone.—Limestone composed of irregular patches and ramifications of granular magnesian rock of the Oregon type, interpreted as branching fucoids and presumably algal in origin, distributed through a matrix of dense limestone of the Tyrone type. On weathering, the surface becomes honey-combed by differential leaching of the more porous "Oregon" rock. Fossils are not common; the most characteristic are *Maclurites bigsbyi*, *Escharopora ramosa*, *Rhinidictya trentonensis*, and various cephalopods. *Cryptophragmus antiquatus* characterizes a 65-foot or thicker zone in the upper 90 feet.[4] Approximately 300 feet is exposed above drainage.

[4] G. G. Huffman, "Middle Ordovician Limestones from Lee County, Virginia, to Central Kentucky," *Jour. Geol.*, Vol. 53 (1945), pp. 145–74.

The *Cryptophragmus* beds are a basis for correlation with the Pamelia and Lowville (Black River) of New York.[5]

The unexposed section below has been described by Freeman,[6] who recognized the following.

A green bentonitic shale marking the top of the Knox which serves as a good marker. An interval from the base of the Lexington to the Knox of 500–600 feet in the central Bluegrass which thickens to 1,000 feet in the southeastern part of the state.

The St. Peter has not been recognized in wells on the west side of the arch, is spotty on the crest and apparently consistently present on the eastern flank. The greatest thickness observed is 63 feet in Estill County. Other reported occurrences seem to be lenses of similar sand in the upper Knox.

Oregon limestone ("Kentucky River marble").—The Oregon consists of gray to cream and buff-colored, granular, magnesian limestone. It is barren of fossils. The formation is 15–35 feet thick. The Oregon is regarded as the equivalent of the Carters of Tennessee which, as indicated in the following notes on the bentonite layers, in its thickening and thinning is a contemporaneous lithologic facies of the Tyrone.

Tyrone limestone ("Birdseye limestone" of Linney).—The Tyrone is dense, gray, dove- or cream-colored limestone, breaking with conchoidal fracture, and with small facets of coarsely crystalline calcite scattered through it. On weathering, the surface becomes white and the darker facets are conspicuous, giving rise to the name "Birdseye." Nodules and thin sheets of gray chert occur in the upper beds. Here and there a bed of the Camp Nelson type is present. Southeast of Nicholasville in Jessamine County, a 15-foot zone of gray, medium- to coarse-grained limestone, similar to that of the Curdsville, occurs 35–45 feet below the top. *Tetradium* and intraformational breccias occur both above and below it.

A bed of bentonite, a greenish clay, occurs 15–25 feet below the top. This is a consistent horizon marker in deep drilling in the state, and is the Pencil Cave of southern and western Kentucky.[7]

This bentonite which is the principal and most consistently developed bed, was first recognized by Ulrich.[8] It ranges in thickness from a few inches to 5 feet.

Two other beds are well known:

1. A bentonitic shale has been observed in many localities at the Tyrone-Curdsville contact. At Curdsville Station (abandoned) on the Cincinnati-Southern Railroad in northern Mercer County, it is approximately 2 feet thick. Elsewhere the Curdsville is in sharp contact with the Tyrone, and in places the two are firmly cemented together. This welded disconformity has

[5] G. G. Huffman, *ibid.*, pp. 145–74.

[6] L. B. Freeman, "Present Status of St. Peter Problem in Kentucky," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 12 (December, 1939), pp. 1836–43.

[7] In the eastern part of the state the term is used for a green clay shale break between the Glen Dean and lower Chester.

[8] E. O. Ulrich, "A Correlation of the Lower Silurian Horizons of Tennessee and of the Ohio and Mississippi Valleys with Those of New York and Canada," *Amer. Geol.*, Vol. 1 (1888), pp. 305–15; Vol. 2 (1888), pp. 39–44.

FIG. 2.—West-east series of sections.

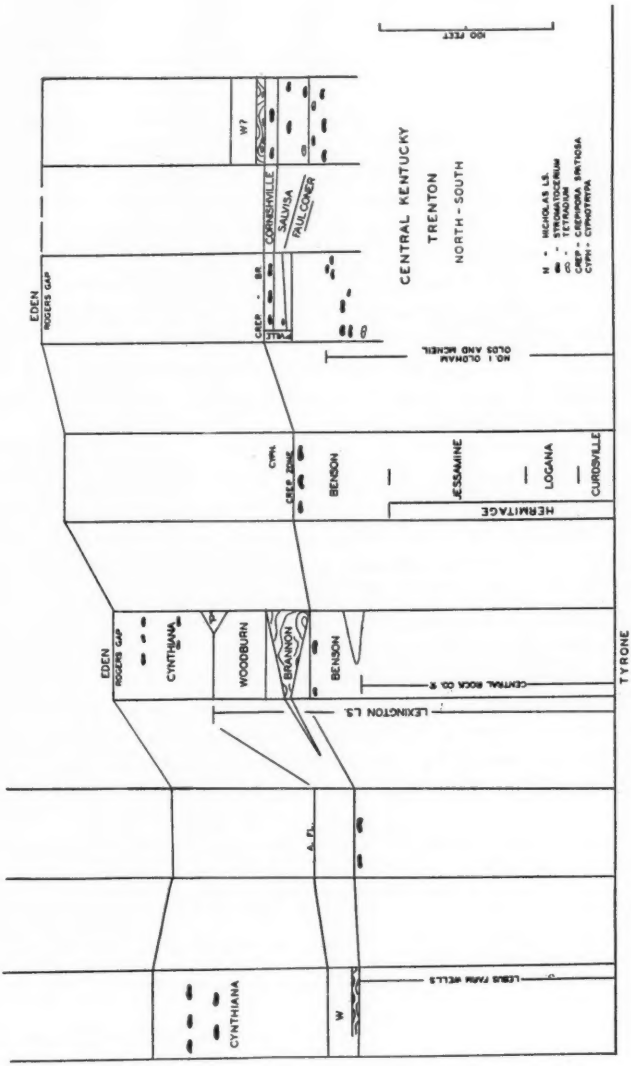

FIG. 3.—North-south series of sections.

FIG. 2.—West-east series of sections.

been regarded as rather unique. Locally, fragments of the Tyrone are included in a Cursdville matrix in the lower foot of the formation. On the basis of position in the section, as well as appearance, it seems to be the same as the ash layer mentioned by Butts[9] from Birmingham, Alabama, and is Born and Burwell's[10] "Mud Cave" of the Cumberland River oil field. Both this and the higher bentonite are underlain by a few inches of gray chert.

2. A thin seam has been recognized by Young[11] 10 feet above the base of the Tyrone. It attains a maximum thickness of 1 foot.

The recognition of the "Mud Cave" at the top of the Carters limestone and the "Pencil Cave" within it in Clay County, Tennessee,[12] in a section where the Tyrone is "absent" indicates that the upper Carters here is the equivalent of the Tyrone elsewhere. These are the two main bentonite layers of the Kentucky Ordovician previously mentioned. They are also apparently represented in the upper Eggleston of Lee County and elsewhere in Virginia.

Fossils in the Tyrone are few and include such forms as *Strophomena incurvata*, *Hesperorthis tricenaria*, *Rhinidictya nicholsoni*, *Phyllodictya frondosa*, *Escharopora ramosa*, *Leperditia fabulites*, *Tetradium cellulosum* (rather common in the upper part), and the cephalopods *Endoceras*, *Actinoceras*, and *Cameroceras*.

Though for years regarded as Lowville, these beds are now apparently assigned to the lower Trenton.[13]

LEXINGTON LIMESTONE

As originally defined by Campbell,[14] the Lexington limestone included beds intervening between the High Bridge and his Flanagan chert. There is some confusion in Campbell's definition of the High Bridge-Lexington boundary, though as it is now used, it is the sharpest stratigraphic boundary in the whole section. He included the upper part of the Birdseye limestone (Tyrone) in the Lexington. The first adequately described section is A. M. Miller's[15] Old Crow Distillery section and this has since served as the standard Trenton section. In it the Brannon, Woodburn, and "Perryville" beds were included in the Lexington. The writers have followed this usage of the term and find it satisfactory.

The divisions of the Lexington limestone are in part faunal zones and in part lithologic units. They have been described in some detail by Miller and Foerste

[9] Charles Butts, "Geology of Alabama, the Paleozoic Rocks," *Alabama Geol. Survey Spec. Rept. 14* (1926), pp. 41–230.

[10] K. E. Born and H. B. Burwell, "Geology and Petroleum Resources of Clay County, Tennessee," *Tennessee Dept. Conservation, Div. Geol. Bull. 47* (1939). 188 pp.

[11] D. M. Young, "Bentonite Clay Horizons and Associated Clay Layers of Central Kentucky," *Univ. Kentucky Research Club Bull. 6* (1940), pp. 27–31.

[12] K. E. Born and H. B. Burwell, *op. cit.*

[13] G. G. Huffman, *op. cit.*, pp. 145–74.
Charles Schuchert and C. O. Dunbar, *Historical Geology*. John Wiley and Sons (1941).

[14] M. R. Campbell, "Description of the Richmond Quadrangle (Kentucky)," *U. S. Geol. Survey Geol. Atlas Folio 46* (1898). 4 pp.

[15] A. M. Miller, "Geology of the Georgetown Quadrangle, Kentucky," *Kentucky Geol. Survey*, Vol. 1, Pt. 1 (1913), pp. 317–51.
———, "Geology of Franklin County, Kentucky," *ibid.*, Vol. 2, Pt. 3 (1914), pp. 7–87.

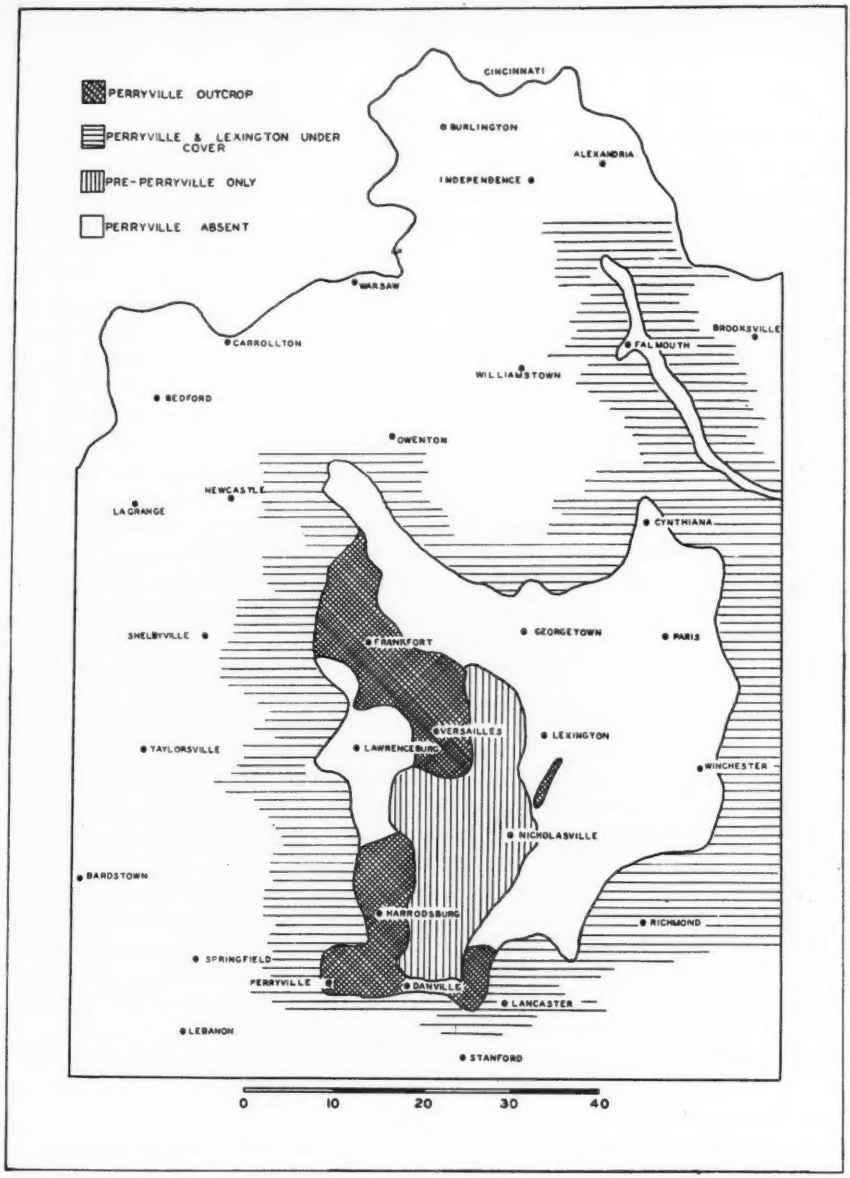

FIG. 4.—Distribution of the Perryville in central Kentucky. Perryville is found in two great areas. That of Harrodsburg-Danville region is true Perryville and has been recorrelated with Benson. That of Frankfort-Versailles vicinity is post-Woodburn in age and has been renamed Devil's Hollow division of upper Lexington.

and more recently by the writers. Their general lithologic character is that of fossiliferous thin- to medium-bedded gray crystalline limestone and some shale. The Brannon, with its lithologic characteristics, a fine-grained gnarly siliceous limestone yielding a residuum of chert on weathering, has generally been designated as the mid-Lexington. It is the Flannagan chert of Campbell. A division into lower middle and upper is approximately as far as formational designation should go.

LOWER LEXINGTON LIMESTONE

Curdsville limestone.—Coarsely crystalline, medium- to heavy-bedded gray limestone with much light gray chert. Locally a basal breccia with Tyrone fragments is included in a Curdsville matrix. Characteristic fossils include *Hesperorthis tricenaria, Dinorthis pectinella, Rhynchotrema subtrigonale, Streptelasma profundum, Sowerbyella curdsvillensis,* and *Dalmanella bassleri.*[16] The Curdsville fauna is now recognized in the basal Hermitage of central Tennessee[17] and in Lee County and elsewhere in southwestern Virginia. It is about 20 feet thick.

Logana formation.—Crystalline, in some localities siliceous, limestone and shale. *Dalmanella bassleri* and *Prasopora falesi* are common, and *Heterorthis clytie* is regarded as characteristic but is not common. The formation is not readily differentiated from the Jessamine in either faunal or lithologic characteristics. Near the top there is commonly a mólluscan horizon where *Modiolodon oviformis, Sinuites obesus, S. pervolutus,* and *Lophospira obliqua* are abundant. It is 30–35 feet thick.

This formation in Kentucky has gone under the name Hermitage, correlated with that formation in Tennessee with the additional assumption that the Jessamine and Curdsville were absent in that state. Although not recognized there as distinct units, it is reasonably certain that the Hermitage of Tennessee[18] is the Curdsville-"Hermitage"-Jessamine succession of Kentucky. Thus, the re-use of the term Logana.[19]

Jessamine limestone (replacing the name Wilmore).—The Jessamine is a zone of abundant and typical *Prasopora simulatrix* (also *P. falesi*) together with *Dalmanella bassleri* (*D. fertilis*), *Rhinidictya neglecta, Liospira americana,* and *Hebertella frankfortensis.* Throughout much of Jessamine and Fayette counties, at least, the top of the formation is marked by a few feet of hard, fine-grained limestone containing a profusion of *Lophospira* and other mollusks, also an abundance of ostracods, principally *Ceratopsis.* In this area something of a recognizable

[16] The name *Dalmanella fertilis* probably should be used.

[17] C. W. Wilson, "Curdsville Limestone Zone of the Hermitage Formation (Trenton Group) in Central Tennessee" (abstract), *Bull. Geol. Soc. America,* Vol. 49 (1938), pp. 1923–24.
———, "Hermitage Formation (Trenton Group) in Tennessee" (abstract), *ibid.,* Vol. 50 (1939), pp. 1993–94.

[18] C. W. Hayes and E. O. Ulrich, "Description of the Columbia Quadrangle (Tennessee)," *U. S. Geol. Survey Geol. Atlas Folio 95* (1903). 6 pp.

[19] G. G. Huffman, *op. cit.,* pp. 145–74.

formational boundary is present. *Sowerbyella rugosus* occurs in the lower part of the formation and again in the uppermost beds. It is 75–80 feet thick.

Benson limestone.—The association of *Rhynchotrema increbescens* and *Hebertella frankfortensis* in abundance is more or less characteristic of the Benson limestone, though both occur lower in the section. The uppermost beds are characterized by an assemblage that includes *Stromatocerium pustulosum, Dinorthis ulrichi, Strophomena vicina,* and *Cyphotrypa frankfortensis.* Associated with the *Stromatocerium* reef in parts of Fayette and Jessamine counties is an equally diagnostic reef composed of the contorted laminae of an undescribed species of *Ceramoporella(?).*

Two to four feet of even-bedded Brannon-like limestone, 20–30 feet below the top of the Benson, forms a recognizable member in southern Jessamine and Fayette, and northern Garrard counties. This limestone yields a zone of residual chert similar to that of the typical Brannon. It can easily be confused with the latter but underlies the *Stromatocerium* horizon. Further, in this particular area the Brannon is not a chert producer. It is recognized as far north as Georgetown in Scott County and has been observed near Frankfort.

It is 40–75 feet thick, the variation not being significant. While the upward termination of the *Dalmanella-Prasopora* zone varies in position, the combined Jessamine-Benson thickness remains essentially the same. *Dalmanella bassleri* is known to be locally abundant to within 20 feet of the top of the Benson. Thus there are two faunal zones, the contact between which is not a stratigraphic plane.

South from the central part of the Bluegrass the character of the upper Benson changes, giving rise to a facies which may be referred to as the Perryville facies but which until recently[20] was regarded as post-Woodburn in age and referred to as the Perryville formation. The Perryville, as it was known, is absent from much of the area of mid-Ordovician outcrop in central Kentucky. It is restricted, with minor exceptions, to two areas referred to in this paper as the Danville-Harrodsburg, or southern area, and the Versailles-Frankfort area. The latter area contains rocks chiefly post-Woodburn rather than true Perryville in age. The southern area is the type for the Perryville[21] formation and its three divisions, which in descending order, are as follows.

Cornishville.—Crystalline limestone of the ordinary Lexington type, characterized by the upper Benson *Stromatocerium* fauna. Thickness, 6–8 feet

Salvisa (upper Birdseye of Linney).—Compact brittle rock suggesting the Tyrone (lower Birdseye). Thickness, 0–15 feet

Faulconer.—Massive light gray porous coarsely crystalline limestone. Thickness, 0–15 feet

It has recently been shown[22] that the Cornishville with its supposedly recurrent upper Benson fauna is actually uppermost Benson and thus the entire

[20] A. C. McFarlan and W. H. White, "The Perryville Formation of Central Kentucky," *Proc. Geol. Soc. America* (1946).

[21] A. W. Foerste, "Strophomena and Other Fossils from Cincinnatian and Mohawkian Horizons, chiefly in Ohio, Indiana, and Kentucky," *Denison Univ. Sci. Lab. Bull.* 17 (1912), pp. 17–172.

[22] A. C. McFarlan and W. H. White, *op. cit.*

Perryville is a Benson facies. With the re-correlation of the Perryville, *Stromatocerium* and associated fossils of the upper Benson form a well marked zone in two-thirds of the area of outcrop of the Trenton. In the southern Bluegrass it is set off by the distinctive lithologic characteristics of the Salvisa below. In the central Bluegrass it contrasts with the chert débris from the Brannon (Flannagan) above. It is well to point out, however, that in the southern counties *Stromatocerium* associated with *Tetradium* is fairly common also in the Salvisa, Faulconer, and the rocks below. The change to the Perryville lithologic characteristics is gradual, the Jessamine and much of the Benson section becoming finer and harder on the south, and developing into the Dove and Cannon rock of Tennessee.

Fossils commonly mentioned as characteristic of the Salvisa and Faulconer members occur largely in the Versailles-Frankfort area and are thus not Perryville in age.

MIDDLE LEXINGTON LIMESTONE

Brannon limestone.—The Brannon is fine-grained siliceous gnarly limestone with much shale in the lower part. On weathering it gives rise to a conspicuous zone of chert drift and forms the greater part of Campbell's Flanagan chert.[23] It ordinarily does not carry chert nodules as such. The thickness listed by Campbell seems to indicate that some Woodburn was included. Lithologic descriptions indicate otherwise. In its normal development, fossils are not common excepting in shaly zones and there they commonly show some dolomitization. The Brannon contains the sponges *Brachiospongia digitata* and *Pattersonia aurita*. The characteristic gnarly structure in many places seems to be a "mud flow" structure, at other places an involved cross-bedding. Its thickness is 15–20 feet, in places 30 feet.

The formation described in the preceding paragraph is typical Brannon, as shown at Brannon Station and in Clark County. North of Lexington in Bourbon County, typical Brannon disappears as a lithologic unit and its position in the section is not well marked excepting for the occurrence of *Stromatocerium* or equivalent diagnostic fossils of the uppermost Benson. Southwestward the Brannon develops an argillaceous, less siliceous facies with no chert. This has caused some confusion where the chert-producing "Brannon-like" zone of the Benson is present below. Farther southwest this facies becomes highly fossiliferous and rubbly with an abundance of bryozoans of which *Crepipora spatiosa* is the most distinctive. Associated with it is a profusion of *Peronopora milleri*, *Eridotrypa aedilis*, and others. This *Crepipora* zone was formerly classified with the Cynthiana and is referred to in subsequent paragraphs under that heading.

Woodburn phosphatic member.—Crystalline limestone having an unusually high phosphorus content. The most useful fossils are *Columnaria halli* and *C. alveolata* var., associated with *Platystrophia colbiensis*, *Constellaria teres* (locally

[23] M. R. Campbell, *op. cit.*

very abundant), *Cyclora minuta*, and *Rhynchotrema increbescens*. It is 10–40 feet thick.

In the southern Bluegrass this zone is apparently represented in the so-called *Cyphotrypa-Prasopora* zone of the "pre-Greendale" Cynthiana. There is little that can be regarded as normal Woodburn in the southern Bluegrass.

PROBLEM OF UPPER LEXINGTON

On the north in Bourbon, Harrison, Franklin, and Fayette counties, the Brannon fades in a short distance as a useful lithologic unit. The Woodburn also thins. The recognition of these beds becomes more difficult as the Brannon wedges out (lithologic change), but the horizon is still well marked wherever *Stromatocerium* and its associates of the upper Benson are present. In northern Franklin County and in the vicinity of Cynthiana, the horizon is recognized with some difficulty. *Stromatocerium* has not been found and *Dinorthis* and *Strophomena* are not common.

A similar thinning of the upper Lexington develops toward the east in Clark County, but whereas *Stromatocerium* is uncommon, the Flanagan chert is well developed and *Dinorthis* and *Stromatocerium* are common. The beds have already been recognized[24] as disappearing toward the south and southwest.

The problem to be solved is the relationship between the thinning upper Lexington and a corresponding thickening "Cynthiana."

"*Perryville*."—It has been shown earlier that the beds of Woodford and Franklin counties referred to as Perryville are not Perryville. They are mostly post-Woodburn in age whereas the Perryville is upper Benson.

"*Faulconer*."—Faulconer is porous coarsely crystalline light gray massive limestone containing in its typical development a crowded mass of gastropod shells, chiefly *Bellerophon troosti*, *Oxydiscus subacustus*, and *Lophospira medialis*. Silicification in weathering gives rise to a conspicuous fossiliferous chert horizon.

"*Salvisa*."—The so-called Salvisa is compact limestone suggesting the Tyrone. Characteristic fossils are *Isochilina jonesi*, *Leperditia* (several species), and *Orthorhynchula linneyi*. Locally it is softer and more argillaceous. *Isochilina* occurs more abundantly in this type of rock.

Other than in the Woodford and Franklin county area, where these beds are not uniformly present, small areas are known north of Paris and along the West Hickman fault zone southeast of Lexington. Rather than being considered indicative of unconformity, these beds may better be regarded as local lenses having distinctive lithologic characteristics in either the upper Woodburn or lower Cynthiana or both. There is some evidence to indicate this, and they are interpreted as such in this paper. There is ample evidence that these two divisions are lithologic facies, in part contemporaneous.

[24] A. C. McFarlan, "Stratigraphic Relationships of Lexington, Perryville, and Cynthiana (Trenton) Rocks of Central Kentucky," *Bull. Geol. Soc. America*, Vol. 49 (1938), pp. 989–96.

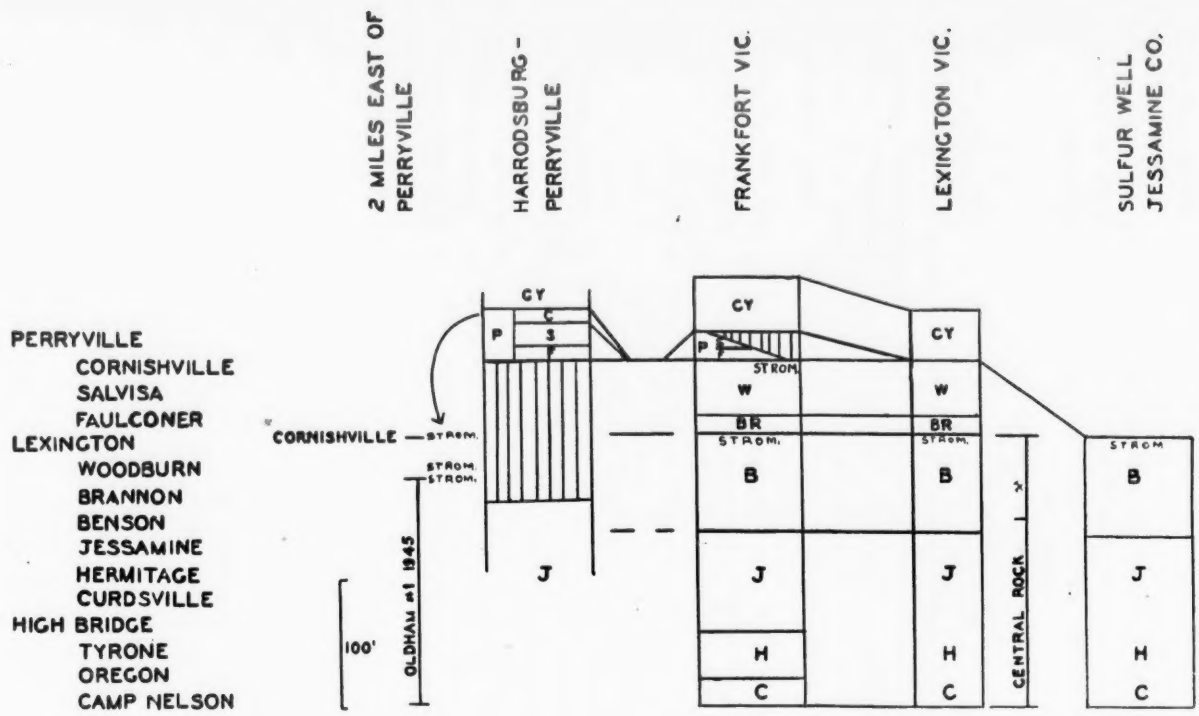

FIG. 5.—Sections showing revised correlation of Perryville. Perryville in Harrodsburg-Perryville region, as heretofore interpreted, rested unconformably on lower Benson. This becomes conformity as Cornishville becomes uppermost Benson. Interval from top of Benson to Tyrone is given by drill record of Oldham No. 1, two miles east of Perryville. In Frankfort section, "Perryville" is post-Woodburn and referred to as Devil's Hollow division of upper Lexington in this paper.

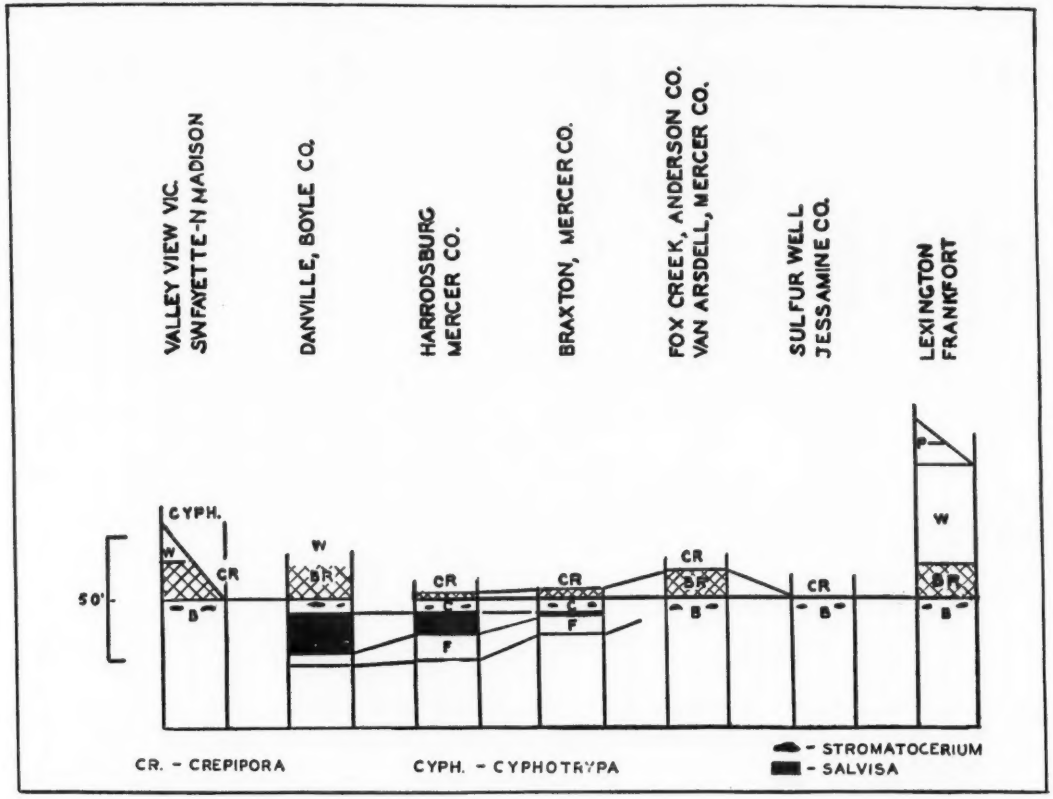

FIG. 6.—Section showing Benson-Perryville, and Brannon (Br)-*Crepipora* zone (Cr) relationships. Salvisa wedges out north near Braxton in Mercer County, a wedging facies. *Crepipora spatiosa* zone, fossiliferous facies of Brannon, in places rests on Benson and elsewhere on lower Brannon. Near Valley View in southwest Fayette, southeast Jessamine, and northern Madison counties, the *Crepipora-Cyphotrypa* succession of "pre-Greendale Cynthiana" gives way to normal Brannon-Woodburn.

With the term Perryville a synonym of Benson, a new name for the post-Woodburn "Perryville" of the Frankfort-Versailles area is necessary. An excellent development of these beds having a thickness of 25 feet is found along the Devil's Hollow road a few miles west of Frankfort, and the name Devil's Hollow division of the upper Lexington limestone is proposed for them. It includes 15 feet of the "Faulconer" rock and 10 feet of the "Salvisa." No names for the two subdivisions are proposed other than lower and upper. The sections here and elsewhere around Frankfort are given in Figure 7.

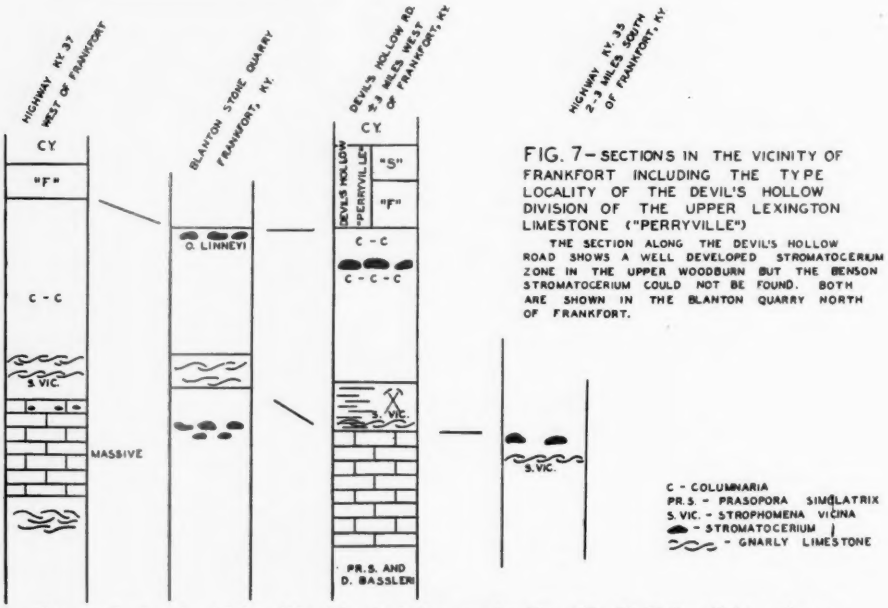

FIG. 7—SECTIONS IN THE VICINITY OF FRANKFORT INCLUDING THE TYPE LOCALITY OF THE DEVIL'S HOLLOW DIVISION OF THE UPPER LEXINGTON LIMESTONE ("PERRYVILLE")

THE SECTION ALONG THE DEVIL'S HOLLOW ROAD SHOWS A WELL DEVELOPED STROMATOCERIUM ZONE IN THE UPPER WOODBURN BUT THE BENSON STROMATOCERIUM COULD NOT BE FOUND. BOTH ARE SHOWN IN THE BLANTON QUARRY NORTH OF FRANKFORT.

FIG. 7.—Sections in vicinity of Frankfort including type locality of Devil's Hollow division of upper Lexington limestone ("Perryville").

In the Devil's Hollow section the Benson *Stromatocerium* reef is not developed, and this is also true in the exposed sections along Kentucky Highway 37 and United States Highway 60 west of town. It is abundantly present in the sections on Kentucky Highway 35 north of town and in the near-by Blanton quarry, and also on Kentucky Highway 35 south of town. In this latter section *Strophomena vicina* is present in an 18-inch gnarly Brannon-like layer 6 feet below the *Stromatocerium* reef.

It should also be repeated that the supposedly characteristic "Faulconer" and "Salvisa" fossils indicated previously are from these particular beds and not from the Perryville proper.

CYNTHIANA FORMATION

The Cynthiana consists of fossiliferous limestone and shale 40–100 feet thick varying in character in different parts of the area. Several divisions have been named, but their facies change from place to place and there has been considerable confusion. Many of them could well be discarded.

The typical Cynthiana is well shown in the Old Crow Distillery section and in exposures around Lexington. It is fossiliferous, crystalline limestone and shale, the shale commonly dominant. The characteristic fauna includes *Cyclonema varicosum, Eridotrypa briareus, E. aedilis, Orthorhynchula linneyi, Hebertella occidentalis, H. sinuata, H. subjugata, Constellaria emaciata, C. florida, C. fischeri, Heterotrypa parvulipora, Dekayella foliacea, Escharopora falciformis, E. maculata, Rafinesquina winchesterensis, R. alternata* and *Platystrophia colbiensis*. Because of its large shale content, the Cynthiana in much of its area of outcrop yields a landscape typical of the Eden shale belt. However, the upper part in the northern area is a quarry rock. The Cynthiana has been separated into several divisions.

Greendale limestone.—This name was given rocks exposed in a railroad cut near Greendale Station on the Southern Railroad a few miles north of Lexington. There has been little precision in its use. In general, it has been used for the rather fossiliferous limestones and shales around Frankfort and Lexington having the fauna listed in the preceding paragraph. In 1909, Foerste[25] defined the Greendale as including that part of the Cynthiana below the Nicholas limestone. However, because of the wedging-out of the Nicholas, the Greendale lithologic characteristics and fauna continue to near the top of the formation. At the type locality much of the exposed section is the Nicholas.

Millersburg limestone.—The Millersburg is very fossiliferous, argillaceous, and characteristically rubbly limestone of the eastern and northeastern flank of the dome. It is marked at the base by an abundance of *Allonychia flanaganensis* in a zone 6–8 feet thick and is bounded above by the Nicholas limestone. It is more or less equivalent to the Greendale and similarly constitutes the body of the formation as the Nicholas limestone above wedges out southward.

Nicholas limestone.—The Nicholas limestone is medium- to coarse-grained, medium to comparatively heavy-bedded quarry rock, typically developed in Nicholas County, Kentucky, where it is 35 feet thick, and overlies the Millersburg. It is a widespread facies and includes the quarry rock at Cynthiana, the River Quarry beds at Cincinnati, and probably the upper and greater part of the railroad cut at Greendale Station. On the south it grades into argillaceous rock. It is overlain by the Rogers Gap and is partly included in it.

Stromatocerium associated with *Columnaria* and in some places with *Tetradium* is conspicuous in a ledge 40–50 feet above the base of the Millersburg and just below the Nicholas in Clark County and parts of Bourgon County. This has some significance for stratigraphic purposes as it seems to correspond with a similar oc-

[25] A. F. Foerste, "Preliminary Notes on Cincinnatian Fossils," *Denison Univ. Sci. Lab. Bull. 14* (1909), pp. 208–32.

currence in the Stones Road railroad cut 3 miles south of Lexington, 20 feet above the bottom of the Cynthiana. Here, though, is a fully developed upper Lexington limestone. This zone helps to define the downward thickening of the Cynthiana east and north.

At Cynthiana in Harrison County, a *Stromatocerium-Tetradium* zone occurs 20–25 feet below the Eden. This is a higher zone and apparently is represented at the Lexington reservoir 25 feet below the Eden.

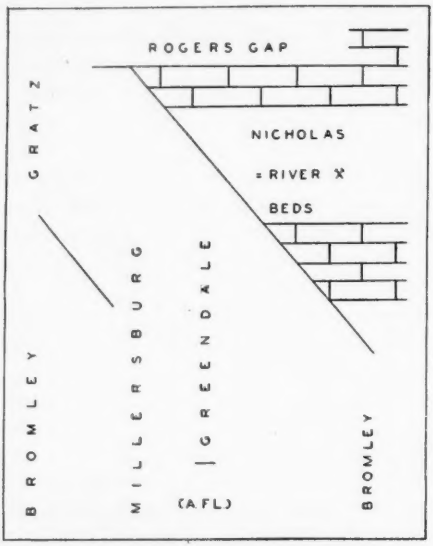

FIG. 8.—Divisions of Cynthiana formation.

Rogers Gap beds.—The Rogers Gap is thin- to medium-bedded limestone and shale with a distinctive fauna characterized by the presence of *Eridorthis nicklesi*, *Clitambonites rogersensis*, *Leptaena gibbosa invenusta*, and a limited number of *Merocrinus* stem plates. These stem plates are abundant in and a characteristic marker of the overlying Fulton. *Hallopora onealli* and *H. onealli sigillaroides* are present in limited numbers in the central and southern counties, and locally become common. This introduces an Eden aspect to the fauna. It is everywhere present throughout the area of Cynthiana-Eden outcrop. In Owen and Henry counties, these beds are essentially barren shale with interbedded fine-grained siliceous and earthy limestones.

Bromley shale.—This name was given to 30 feet of drab and blue shales in the lower part of the bank of the Ohio River at Cincinnati. Some of the shales and fine-grained siliceous, earthy and commonly gnarly limestones of the lower Cynthiana in the northern Bluegrass and also in northern Madison County have been

regarded as Bromley, perhaps not too accurately. Gastropods and pelecypods are particularly common. The Bromley is a facies of the lower Greendale and has its own distinctive fauna peculiar to these fine-grained, earthy limestones and shale.

Gratz shale.—The Gratz formation consists of a rather barren shale and fine-grained earthy limestone forming the upper part of the Cynthiana in Henry and Owen counties. It is an essentially barren facies including in its upper part the Rogers Gap.

Pre-Greendale or *Sulfur Well member.*—This term was used for limestone and shale rich in bryozoans underlying the Greendale and Millersburg in a much thickened Cynthiana section of the southern and southwestern Bluegrass. Particularly characteristic are *Crepipora spatiosa*, *Batostoma minnesotense*, *B. winchelli*, and *Hemiphragma* sp., along with a profusion of *Peronopora* and *Eridotrypa aedilis*. Fifteen to twenty feet above, large specimens of *Prasopora* and *Cyphotrypa* occur. The *Crepipora* zone, resting in different places on the Benson and Brannon and at Harrodsburg and vicinity on the Cornishville, seemed to mark a well defined unconformity. The recent correlation of Benson and Perryville,[26] however, changed the picture as post-Cornishville is merely post-Benson instead of necessarily Cynthiana. The *Crepipora* zone is Brannon in age and apparently the *Cyphotrypa* zone is Woodburn in age. This eliminates the pre-Greendale division of the Cynthiana and gives rise to its recognition as a facies of the upper Lexington, but containing a Cynthiana fauna.

Allonychia zone.—This zone is a rubbly basal zone of Foerste's Millersburg in Clark, Bourbon, and southern Harrison counties. It is not present at Cynthiana. Its occurrence at the base of a thickened Cynthiana coincides with a much thinned Brannon-Woodburn succession. It seems that the *Allonychia* zone, like the *Cyphotrypa* zone, is late Lexington in age. This appears true in spite of the fact that the *Allonychia* fauna with *Cyclonema varicosum* and the large *Heterotrypa* is typically Cynthiana in character.

CINCINNATI SECTION

Little information is available on the River Quarry beds (Nicholas limestone) and underlying beds along the Ohio River banks. Fuller and Clapp[27] mentioned an interval of 150 feet between the Eden and Tyrone. Since the Cynthiana is approximately 100 feet thick, only 50 feet may be assigned to the Lexington limestone or its equivalent. However, a recent well drilled at Latonia[28] shows a normal Tyrone-Eden interval and a conformable Lexington-Cynthiana succession is indicated.

Efforts to subdivide the Cynthiana have not greatly helped to clarify the

[26] A. C. McFarlan and W. A. White, "The Perryville Formation of Central Kentucky," *Proc. Geol. Soc. America* (1946).

[27] M. L. Fuller and F. G. Clapp, "The Underground Waters of Southeastern Ohio," *U. S. Geol. Survey Water-Supply Paper 259* (1912). 228 pp.

[28] Well record through courtesy of L. B. Freeman.

stratigraphic picture. The formation shows many changing lithologic facies and corresponding faunal changes in the general limestone and shale succession. There are many more local variations, fortunately unnamed. The more important conclusions follow.

1. The Rogers Gap at the top seems to be consistently present.

2. The *Allonychia* zone and perhaps more of the lower Millersburg are probably upper Woodburn in age.

3. The so-called pre-Greendale (or Sulfur Well member) has been shown to be late Lexington.

4. All of the named divisions, with the exception of the Rogers Gap, are wedging facies.

Several oil-producing zones occur in the Ordovician in the Cumberland River oil field of Clinton and Cumberland counties, along the axis of the Cincinnati arch. Much of the accumulation is thought due to fracture porosity. The principal horizons are as follows.[29]

Above Pencil Cave
- Fannies Creek-Catheys (Cynthiana)
- Upper Sunnybrook—Cannon, Anderson—Cannon } Perryville
- Lower Sunnybrook—Hermitage

Below Pencil Cave
- Carters and Lebanon (important)
- Ridley (producing zone)
- Knox ("producing zone")

More recently developed and longer-lived is the Granville producing zone of Clinton County. It occurs a short but variable depth (±50 feet) beneath the Garrard sandstone in a region of noticeably thinning Eden and may be Cynthiana in age. The producing zone is a particularly clean limestone, almost a coquina.[30]

STRATIGRAPHIC RELATIONSHIPS

Upper contact.—The Rogers Gap, as indicated, is present throughout the area of outcrop. It is everywhere overlain by the Fulton bed of the Eden which has a closely related, though recognizable, fauna. The latter is best recognized by the *Merocrinus* zone directly beneath the appearance of *Sowerbyella rugosus* in profusion. This *Sowerbyella* zone is one of the best stratigraphic markers of the region. The Fulton has not been recognized in parts of Scott, Bourbon, and Harrison counties[31] and thus a limited disconformity may be recognized. However, this is probably more apparent than real. The relationship is considered one of conformity.

Lower contact.—The lower contact, however, presents a more difficult problem

[29] K. E. Born and H. B. Burwell, *op. cit.*

[30] L. B. Freeman, personal communication

[31] A. C. McFarlan and L. B. Freeman, "Rogers Gap and Fulton Formations in Central Kentucky," *Bull. Geol. Soc. America*, Vol. 46 (1935), pp. 1975–2006; (abstract), *Proc.* (1934), p. 359.

and the answers are not all known. As the Perryville was generally thought to be post-Woodburn in age and an earlier "pre-Greendale" Cynthiana had been recognized above,[32] a well marked unconformity was indicated at the top of the Lexington. However, the Perryville has been shown to be Benson, and much of the earlier "Cynthiana," late Lexington. The unconformity at the base of the Perryville is no longer considered present and the one at the base of the Cynthiana is probably non-existent.

It is hardly a coincidence that the downward thickening of the Cynthiana in the southern, southwestern, eastern, and northern Bluegrass is in the areas of a thinnning upper Lexington interval. This may be interpreted as a Cynthiana invasion of a region of low relief but there is no physical evidence of unconformity. Before the realignment of the Perryville, an unconformity had to be recognized irrespective of the physical evidence. With the removal of this one brick in the stratigraphic structure, the collapse of others followed. The contemporaneity of the lower "Cynthiana" in these several marginal areas with the late Lexington seems to be reasonably certain.

On this basis, earlier comments on mid-Ordovician structure in the region of the Jessamine dome by the senior writer appear not to be substantiated. An unconformable overlap is an overlapping facies. These comments involve only the region (axial) of Ordovician outcrop. A well established geosyncline on the east in the region of the Appalachians in itself indicates an early high in the present region of the Cincinnati arch.[33]

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[32] A. C. McFarlan, "Stratigraphic Relationships of Lexington, Perryville, and Cythiana (Trenton) Rocks of Central Kentucky," *Bull. Geol. Soc. America*, Vol. 49 (1938), pp. 989–96.

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO 8 (AUGUST, 1948), PP. 1647-1657, 5 FIGS., 1 TABLE

KENTUCKY SUBSURFACE[1]

COLEMAN D. HUNTER[2]
Ashland, Kentucky

The following maps have been prepared to show the regional dip and thickness of Ordovician and Cambro-Ordovician formations in eastern Kentucky.

[1] Manuscript received, February 28, 1948.

[2] Geologist, Kentucky-West Virginia Gas Company.

FIG. 1.—Generalized structure on top of Ordovician. Although the control is insufficient to show any details of structure, it is sufficient to show the Ordovician dipping from plus 1,000 feet near its outcrop to minus 4,500 feet in Well F-5018, or 5,500 feet in a distance of 150 miles toward the southeast. The only suggestion of pronounced structure is controlled by Well 54, located in Magoffin County. This well is located on the most pronounced feature in eastern Kentucky—the Paint Creek uplift.

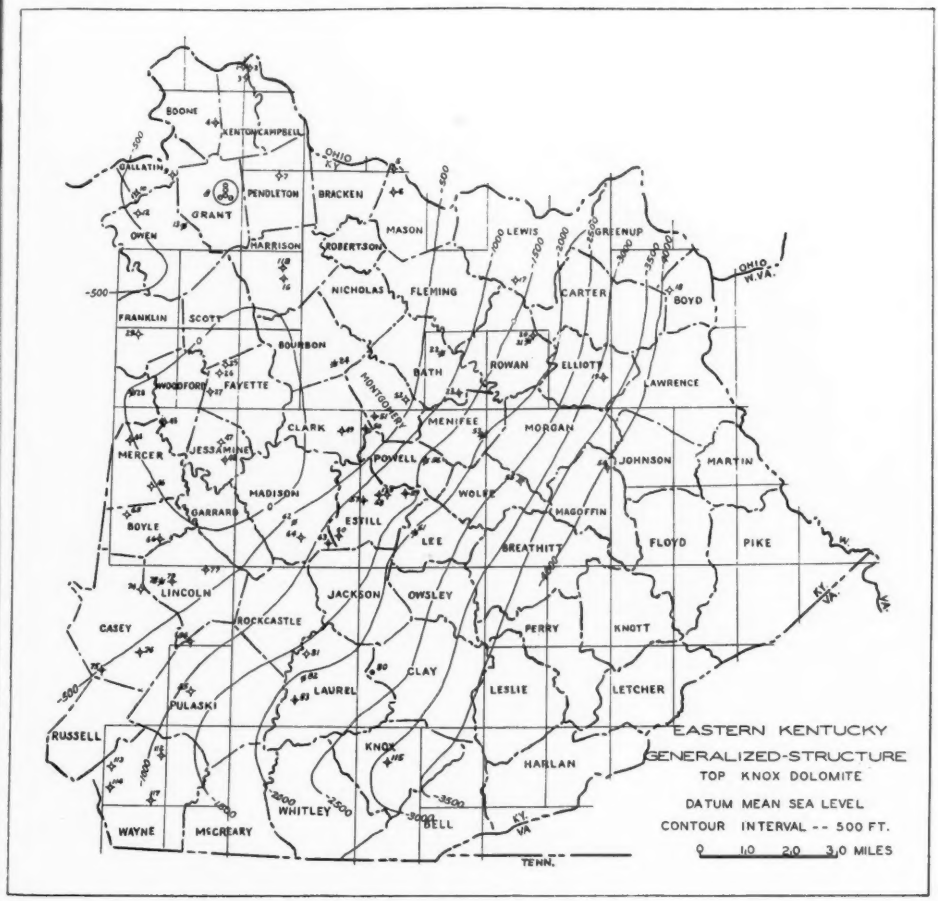


FIG. 2.—Generalized structure on top of Knox dolomite. The highest well (No. 48) on the Jessamine dome in Jessamine County has an elevation on top of the Knox of 372 feet above sea-level. There is a zero closure shown in central Kentucky by the well control on the map. The regional dip southeast is approximately 40 feet per mile as compared with 33 feet per mile on the top of the Ordovician.

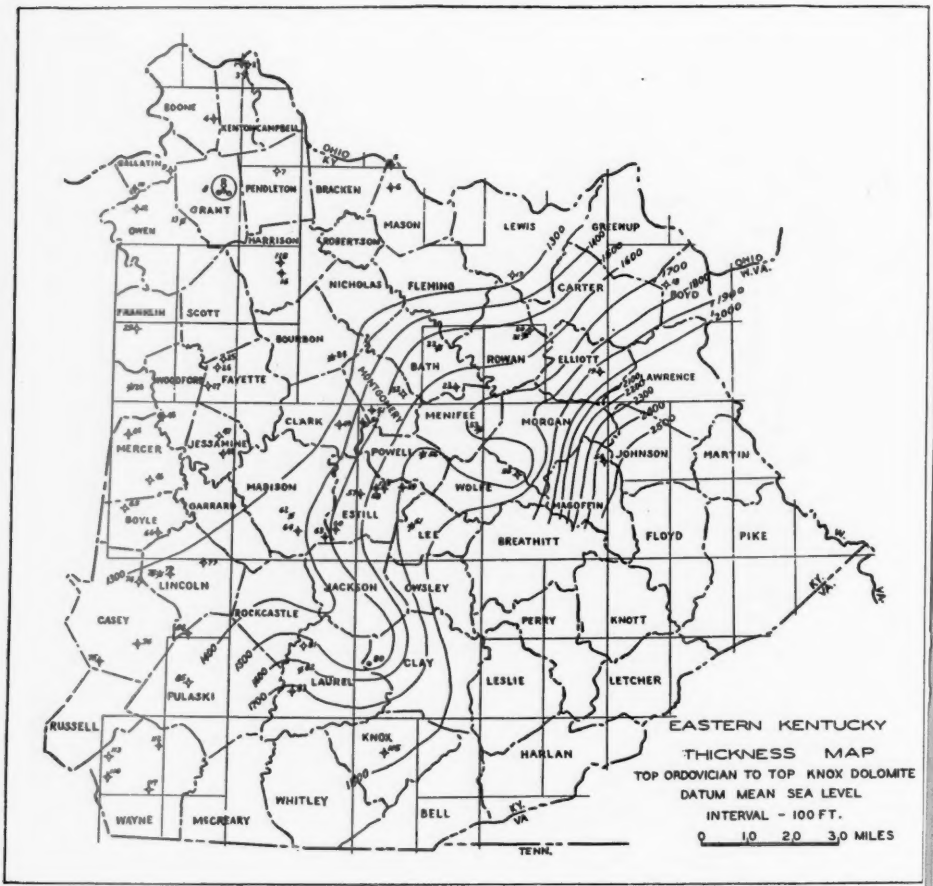


FIG. 3.—Thickness map (top of Ordovician to top of Knox dolomite). This map shows the variation in the interval between the top of the Ordovician and the top of the Knox dolomite, which thickens southeast from 1300 feet in Clark County to 2500 feet in Well 54, which is the most southeastern test in Magoffin County.

FIG. 4.—Thickness map (top of Tyrone to top of Knox dolomite). This map shows the variation in the interval between the top of the Tyrone and the Knox and suggests an isopachous closure in Rowan County if shown in less than 100 feet isopachs.

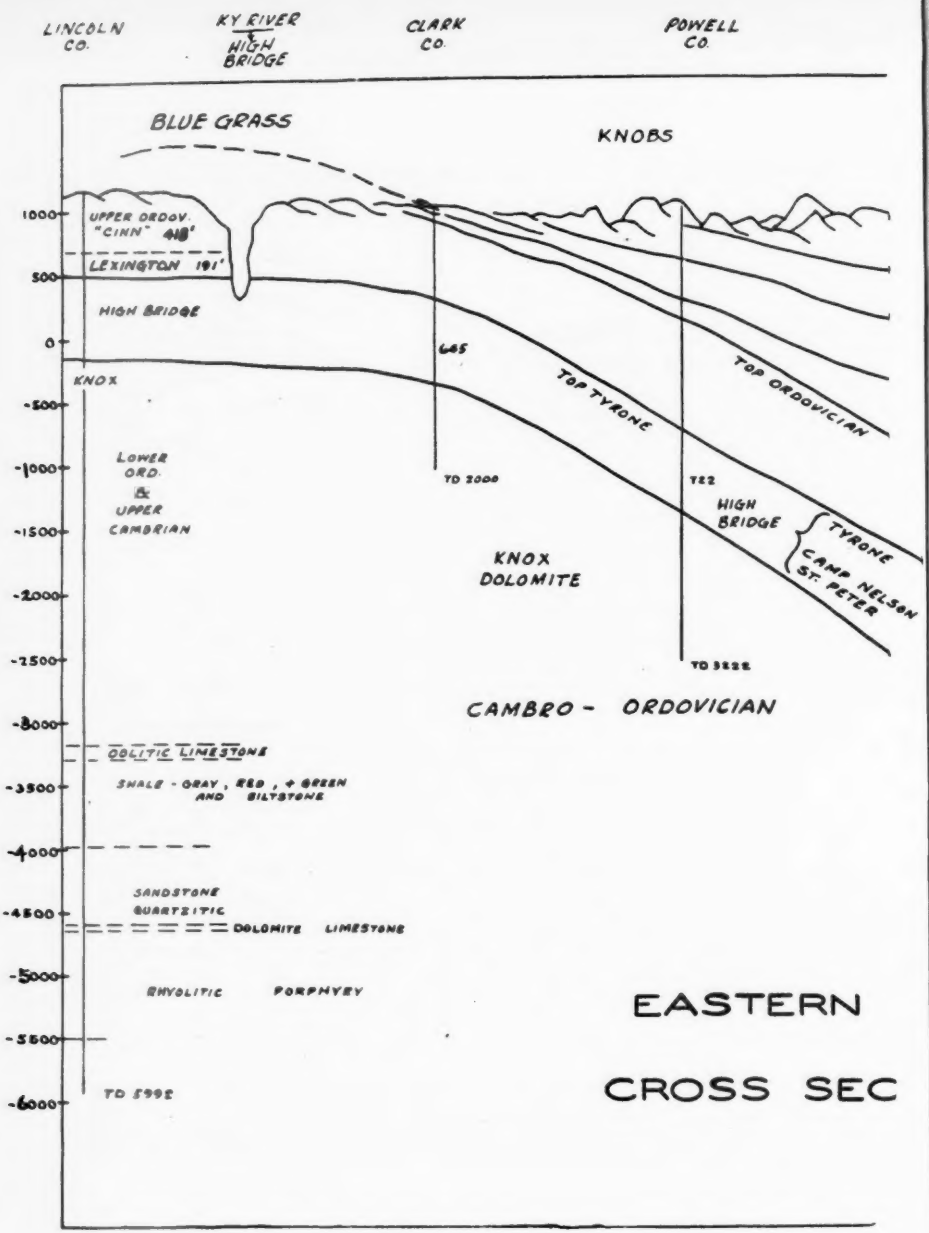
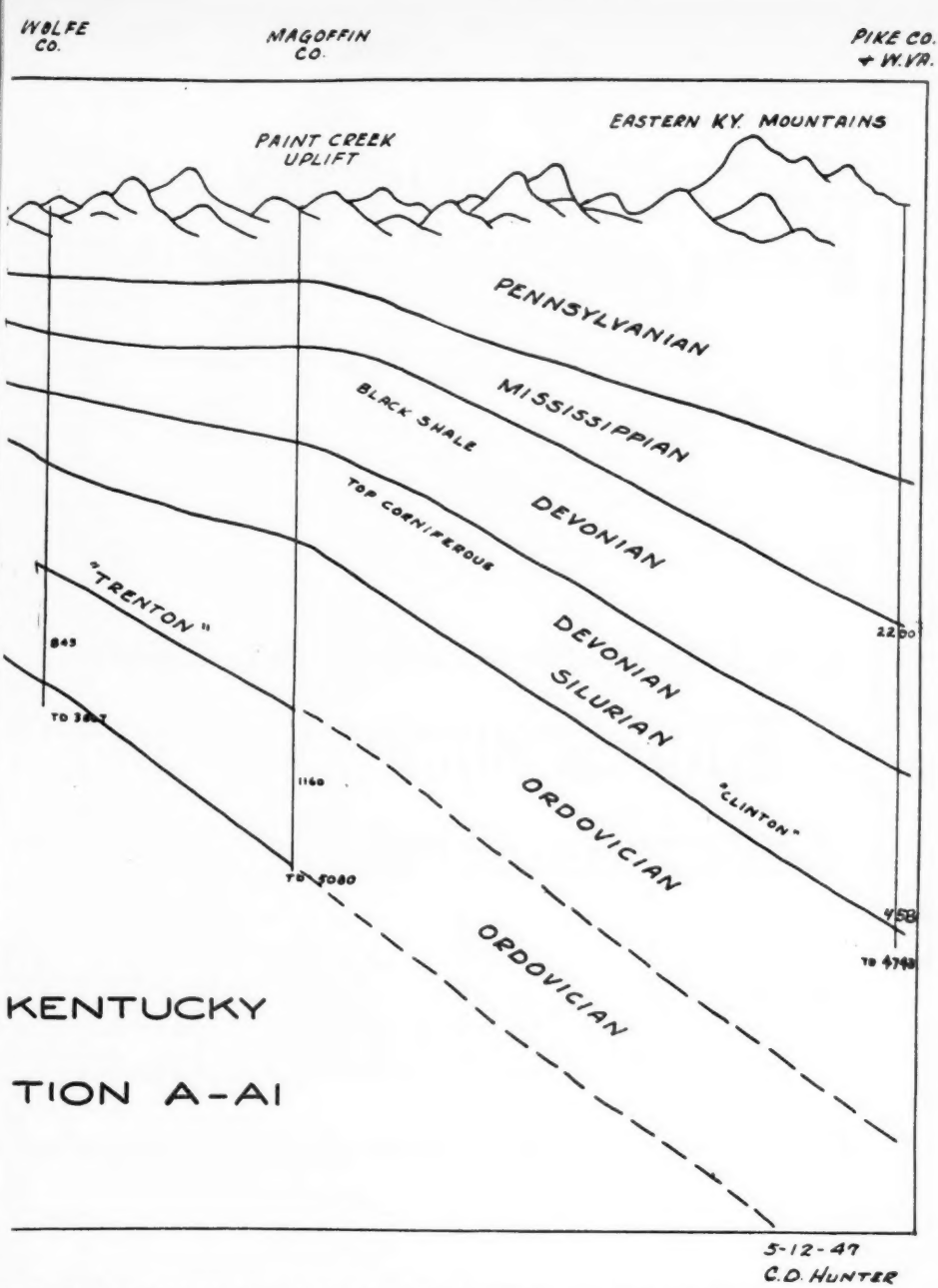


FIG. 5.—This cross section, although greatly exaggerated horizontally, shows the relation of the
mine County, in the rejuvenated Kentucky River gorge, and the 36- to 40-foot dip and 15- to 20-foot



deep Cambrian test in Lincoln County to the oldest Ordovician rocks exposed at High Bridge, Jessa-
thickening of all younger series southeastward in Kentucky. Location of section is shown in Figure 1.

TABLE I

Data on Ordovician and Cambro-Ordovician Wells in Kentucky

Well No.	Farm	County	Location	Elev.	Top Ord.	Top Trenton	Top Tyrone	Top Knox	Total Depth
1	Glass Co. Hemingray	Kenton	21-FF-60	500'				906-	1473'
2	76 Distillery	Campbell	4-EE-61						
3	Latonia	Kenton	10-EE-60						
4	#1 John Grimes	Boone	1-CC-59	930'				1265'	2200'
5	Dover	Mason	17-BB-68	510'					
6	#1 D. F. Weaver	Mason	18-AA-68	918'			712'	1256'	1555'
7	Mollie Edwards	Pendleton	23-BB-62	532'					1600'
8	Dry Ridge Mineral Wells	Grant	16-AA-60	946-				1135-	1135'
9	John Webster	Gallatin	8-AA-57	835'				1051'	1098'
10	Riley	Gallatin	21-AA-55	818'				1200'	1200'
11	Carrollton	Carroll	21-AA-52	460'				1000'	1145'
12	Emmett Johnson	Owen	11-Z-55	661'				1016-	1163'
13	Emmett Harris	Owen	6-Y-58	958'				1104'	1515'
14	#1 Wilhoit	Owen	17-X-56	495'				1522'	2500'
15	Annis Clark	Owen	8-W-56					1490-	1930'
16	Cynthiana	Harrison	3-W-63	723'				785'	1000'
17	Ohio Cities Gas Co.	Lewis	5-W-74	999'	1170'			2446'	2446'
18	American Roller Mills	Boyd	19-W-81	671'	2071'?			4692	4692'
19	J. T. Fraley	Elliott	22-T-78	796'	2107'	2712'	3143'	4027'	4191'
20	Withrow	Rowan	13-U-75	1005'				2844'	
21	Lewis	Rowan	17-U-75	875'				2718'	2787'
22	Rose Run	Bath	21-U-70	700' Est.	30'	407'	960'	1579'	1655'
23	#23 Ewing Heirs	Bath	13-S-71		886'		1900'	2522'	2599'
24	Richard Boardman	Bourbon	10-T-65	865'			209'	808'	959'
25	Walnut Hall	Fayette	2-T-60	876'				798'	1102'
26	Idle Hour	Fayette	14-T-60	954'					
27	Keeneland	Fayette	10-S-59	951'				780'	1004'
28	Ben Bond	Anderson	17-S-56	773'				770'	1565'
29	J. A. Murray	Franklin	9-U-56	516'				725'	1300'
30	#1 Whittaker	Shelby	9-T-54	740'				996'	1501'
31	L & N Railroad Sulphur Well	Oldham	2-W-50	759'				1450'	1555'
32	Barrickman	Oldham	7-W-50	744'					1200'
33	Bradberry	Oldham	14-W-50	750'				1280'	1328'
34	E. C. Klingenfus	Oldham	4-V-49	755'				1495'?	2006'
35	#1 Johns	Jefferson	7-U-46	477'				1000'	1340'
36	Will Vann	Jefferson	12-U-46	495'				1622'?	1622'
37	Sam Armstrong	Jefferson	2-S-45	495'					1730'
38	Senninger	Bullitt	1-S-46					1528'	1665'
39	George Armstrong	Bullitt	21-S-46	435'				1555'	1810'

									1555'	1810'

Well No.	Farm	County	Location	Elev.	Top Ord.	Top Trenton	Top Tyrone	Top Knox	Total Depth
40	W. N. Simmons	Bullitt	10-S-45	458'				1495'	1820'
41	Nat Cochran	Spencer	17-S-49	618'				1258'	1418'
42	Lora Shelburn	Spencer	21-S-49	665'				1262'	1700'
43	Chaplin	Nelson	2-W-52	730'					
44	Andrew Hawkins	Mercer	1-W-55	785'					1400'
45	George Wilhoite	Woodford	17-R-57	676'				622'	1415'
46	Daughtery (Hannah)	Mercer	25-P-57	881'					1500'
47	#1 Hoover	Jessamine	7-W-60	929'				725'	3200'*
48	#1 Coleman	Jessamine	13-W-60	922'				620'	1733'
49	Albert Chism	Clark	17-R-66	931'	Est. 70' above sur.	375'	620'	1270'	2000'
50	W. Z. Eubank	Clark	17-R-67	745'					1610'
51	#1 N. B. Hoskins	Montgomery	4-R-67	819'			504'	1132'	1132'
52	Greenwade	"	15-S-69	769'			880'		1435'
53	J. R. Lyons	Menifee	20-R-72	1118'	1425'		2425'	3118'	3131'
54	#44 L. C. Bailey	Magoffin	6-P-79	1019'	2573'			5060'	5080'
55	#1 D. H. Rose	Wolfe	13-P-74	955'			2825'	3595'	3807'
56	Slug Maloney	Powell	25-W-70	679'				2204'	3222'
57	#1 Masters	Estill	6-S-67		220'	630'	1045'	1784'	1784'
58	Wiseman & Cornett Hrs.	Estill	25-P-68	665'	210'	875'	1050'	1888'	2050'
59	Paul Rogers	Estill	21-P-68	785'	535'		1465'	2145'	2651'
60	#1 Bicknell	Estill	25-M-66	722'				1970'	2124'
61	Bear Track	Lee	12-M-69	1090'	1415'			Est. 3148'	3527'
62	#1 S. W. Lackey	Madison	6-N-64	908'				1467'	1516'
63	#1 J. D. Evans	Madison	2-M-65	726'				1885'	1924'
64	Jonah Alcorn	Madison	23-N-64	1032'				1733'	1733'
65	#1 Olden	Boyle	4-N-56	857'					877'
66	Junction City	Boyle	23-N-57	974'					
67	Nannie Larue	Larue	25-N-46	746'				2170'	2237'
68	Elizabethtown	Hardin	19-S-44						
69	Alonzo Davis	Hart	21-L-46	728'				1903'	1934'
70	#11 W. B. Perkins	Hart	14-1-45	649'				2210'	2244'
71	#1 Hall	Marion	20-L-51	1054'					1670'
72	T. L. Nall	Taylor	18-K-50	684'					2104'
73	Davis (Campbellsville)	Taylor	25-K-51	820'					1300'
74	#1 Elkins	Casey	22-L-56	875'				1299'	1321'
75	Pitman	Casey	25-1-54	885'				1390'	1607'
76	Oscar Nader	Casey	9-1-56	895'				1548'	2000'
77	W. F. Dishon	Lincoln	7-L-59	1059'				1488'	1676'
78	#1 Spears	Lincoln	13-L-57	1125'		418	681	1309'	6117'†

* See K.G.S. Deep Wells Ky. Log 268 P.P.415

† Dry completed Rhyolite Porphry

Well No.	Farm	County	Location	Elev.	Top Ord.	Top Trenton	Top Tyrone	Top Knox	Total Depth
79	#1 Elliott	Lincoln	13-L-57	1030'				1368'	1418'
80	#1 Gilbert Hammond	Clay	2-H-67	1250'	1910'	2240'	2488'	3386'	3400'*
81	Eversole	Laurel	3-I-64	860'					4223'
82	Jones	Laurel	3-H-64	1206'				3280'	3280'
83	Sewell, Nat	Laurel	24-H-64	921'	1165'?	1768'	2060'	2945'	3220'
84	Well at Subank	Pulaski	21-J-58		800'		1200'?		
85	#1 Shoun	Pulaski	7-H-59				1100'	1988'	2000'
86	H. P. Porter	Metcalf	17-H-47	613'				1618'	1785'
87	#2 John Bunch	Barren	16-G-45	807'				1950'	2028'
88	#3 C. E. Glass	Barren	12-F-45	728'				1500'	2320'
89	J. Bertram	Barren	6-D-44	685'				1660'	1694'
90	#1 Motley	Allen	7-D-40	546'				1855'	1912'
91	Davenport (Chapman)	Warren	6-J-37	646'					2925'
92	Lena Doyle	Warren	6-J-38	504'				1735'	2809'
93	#1 Wood	Grayson	25-M-38						
94	Hosapple	Clinton	12-D-52						1522'
95	George Graber	Clinton-Wayne Line	20-D-54	934'					1770'
96	Will May	Clinton	20-D-53						
97	Emily Burchett	Clinton	10-C-52		450'	600'			
98	#1 Parragin	Clinton	14-C-54	905'	418'	525'	960'	1820'	1910'
99	Gibson	Clinton	9-C-54						
100	Simon Shelley	Clinton	19-C-52						
101	Claude Stockton	Clinton	16-C-54	848'	325'				1880'
102	Noah Selvidge	Clinton	17-C-54	850'	325'	547'	921'	1765'	1837'
103	#4 Sherman Flowers	Clinton	20-C-54	963'				1885'	1885'
104	John Selvidge	Clinton	22-C-54	910'					
105	Tom Kogar	Clinton	6-B-55	972'					
106	#1 Hicks	Clinton	10-B-54	902'				1800'	1850'
107	#2 Flowers	Clinton	8-B-54	978'					
108	Litterell	Clinton	3-B-54						
109	J. A. Beatty	Clinton	7-B-54						1900'
110	Jacob Speck	Clinton	7-B-53					875'	1950'
111	W. E. Bertram	Clinton	20-B-53	1006'				1806'	
112	McBeath	Wayne	8-E-57		857'		1657'		2435'
113	#1 Lloyd	Wayne	13-E-55	632'			542'	1561'?	1810'
114	J. W. Barnes	Wayne	8-D-55		480'		1098'		2003'
115	#1 Hammond	Knox	9-E-68	1014'	2616'		3349'	4400'	4908'
116	George Smith	Clinton	23-C-54	897'					
117	J. D. Campbell	Wayne	15-D-57	967'				2040'	2695'

*Oil 3514'-15'. Est. 15 bbls & 200M cu. ft.

Well No.	Farm	County	Location	Elev.	Top Ord.	Top Trenton	Top Tyone	Top Knox	Total Depth
118	#1 Maybrier	Harrison	3-W-63	707'				975'	1364'
119	DuPont	Jefferson	19-V-45					1545'	2086'
120	Walling	Estill	24-P-68					2554'	2730'
	Wells Not Drilled to Knox								
F-4391	Sam Endicott	Martin	Ord. Struct.		4085'				4148'
F-1043	Thos. Fraley	Lawrence	" "	900'	3380'				4975'
F-4271	Jake Smith No. 1	Pike	" "	732'	5185'				5343'
	Martha Stewart No. 1	Carter	" "	650'	2800'				3925'
Co. 74	Jack Whittaker No. 1	Magoffin	" "	949'	2950'				3950'
155	Ferris Begley No. 1	Leslie	" "	1227'	3025'				3150'
F-5368	Joe C. Stamper	Wolfe	" "	900'?	1620'				1818'
F-950	G. B. Rice	Johnson	" "	722'	2825'				2898'
Co.476	W. B. Mullins	Knott	" "	828'	3650'				3706'
F-2357	D. W. Browning	Leslie	" "	1166'	3672'				3954'
Co.5467	John Branham	Pike	" "	1223'	4714'				4847'
F-4433	Va. Ky. C. Co.	Knott	" "	1128'Bar.	3275'				3543'
F-5018	Ford Motors	Pike	" "	1020'	5608'				5743'
Co.5443	Venia Slone	Pike	" "	704'	4804'				4949'

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 8 (AUGUST, 1948), PP. 1658-1663, 3 FIGS.

GEOLOGICAL NOTES

PRELIMINARY REPORT ON RAMONA FIELD, LOS ANGELES AND VENTURA COUNTIES, CALIFORNIA[1]

LOYAL E. NELSON[2]
Los Angeles, California

The Ramona field is in the small but highly petroliferous Santa Clara River basin 45 miles northwest of Los Angeles, California. It immediately adjoins the Del Valle field on the northwest but is a separate and distinct oil accumulation on a different anticlinal fold against whose southeast flank the east-west trending Del Valle anticline abuts and terminates. More specifically, it is located in Sec. 18, T. 4 N., R. 17 W., and Sec. 13, T. 4 N., R. 18 W., S.B.B. & M., in an area of such rugged topography that many wells must be whipstocked to the proper subsurface position to avoid the roughest terrane and landslides. Elevations vary from 1,350 to 2,000 feet above sea-level.

Discovery of the field (named after near-by Ramona Canyon) was made by The Texas Company in its Kern well No. 1, located 991 feet south and 2,251 feet east from the northwest corner of Section 18. It was completed, April 5, 1945, producing from approximately 150 feet of upper Miocene (Delmontian stage) sands at 2,810–3,004 feet, named the Kern zone. The well was swabbed in, flowing 196 barrels per day of 29.3° oil cutting 0.4 per cent and producing through a 4/64-inch bean with 200 pounds tubing pressure and 0 pound (packer) casing pressure and making 70,000 cubic feet of gas per day. The formation at 3,004–3,114 feet consisting of shale and oil sand, was plugged off but was left open in subsequent producing wells.

In brief, the field extension and discovery of additional new zones took place as follows. After a few Kern zone wells were completed in the area surrounding the discovery well, the Universal Consolidated Oil Company drilled Aguirre No. 1 and extended Kern production ¾ mile southwest. Deeper prospecting by the Superior Oil Company-British American Oil Producing Company in their Black No. 1 proved the upper Del Valle zone productive. Successive wells took in even greater penetrations of that particular zone until many found it completely oil saturated to its base. For example, The Texas Company's Kern No. 12 penetrated a Del Valle zone well thickness of 1,400 feet at 3,520–4,920 feet, which is principally oil sand and conglomerate. This, in addition to 130 feet of Kern zone at 3,053–3,310 feet, made a well pumping 245 barrels per day (30 days after com-

[1] This paper is the third in a series sponsored by the A.A.P.G. Pacific Section Committee for Reports on Discoveries, consisting of George H. Roth, William H. Thomas, and Harold H. Sullwold, Jr., chairman. Manuscript received, July 6, 1948.

[2] Chief geologist and engineer, Southern California Petroleum Corporation.

pletion) producing 24° oil, cutting 3.2 per cent water. Other pumping wells in the immediate area had initials as high as 400 barrels per day. On the west, completions range from 50 to 200 barrels per day.

The third and youngest productive zone, named the Black, was discovered by the Bankline Oil Company in its Black well No. 102. This is an upper Miocene (Delmontian stage) sand, approximately 150 feet below the top of the Miocene and 660 feet (well thickness) above the top of Kern zone in the adjacent Black No. 103. The zone, open from 2,190 to 2,332 feet, contains 90 feet of oil sand grading down to conglomerate. The well initially pumped at the rate of 180 barrels per day, of 26° oil, cutting 0.1 per cent.

Discovery of Ramona field is the result of detailed subsurface and surface geological work covering the greater part of a 3-year period.

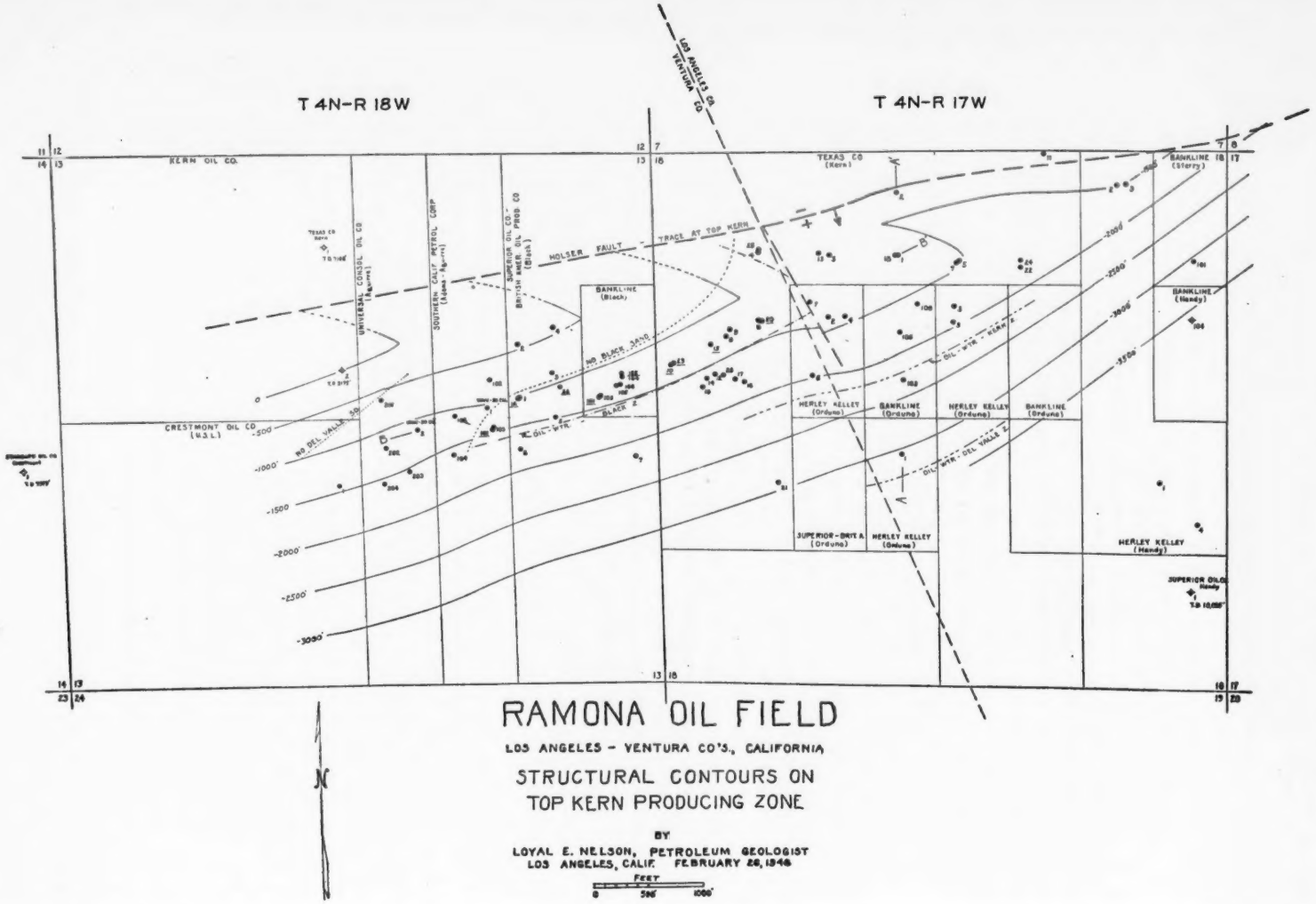
The pool is situated mainly on the southeast-dipping flank of Ramona anticline, a northeast-plunging drag fold developed on the upthrown block of the Holser thrust fault. Dips on this flank average approximately 48°. The fault crops out north of the field, dips SE. 60–75°, and has a throw of approximately 5,000 feet. Sharpness and degree of folding have produced a rather long and narrow productive belt with thick oil measures.

Combinations of structural and stratigraphic conditions combine to trap the oil. Black-zone closure is caused by sand pinch-out along a northeast-southwest line diagonally crossing the plunge of the anticline and a cross fault at the east end. The Kern and Del Valle zones are closed on the north by lensing of sands and the Holser fault, on the west perhaps entirely by lenticularity of sands, on the east and south by plunge and dip with some probable minor faulting involved.

Marine formations of Pliocene and upper Miocene age comprise the stratigraphic section. The youngest beds lie on the south flank of the structure beginning at San Martinez Canyon. These are Pico and are the marine sand and conglomerate equivalent of the continental Saugus beds on the east and northeast.

About 2,000 feet of lower Pico and Repetto siltstone and claystone with interbedded sands and conglomerates make up the remainder of the outcropping Pliocene and extend to a depth of 1,950 feet in the discovery well. This depth marks the base of a pronounced sand and conglomerate which point is selected as the Pliocene-Miocene contact by the writer until more exact paleontological information is obtained.

The upper Miocene beds consist of 2,200 feet of Delmontian-stage gray-brown shales, sands, and conglomerates which include all of the Ramona-field producing zones. Cross section AA' and stratigraphic section BB' demonstrate the relative position and thicknesses of the various lithologic units. The base of the Delmontian and top of the upper Mohnian occur within the shale body near 6,000 feet in Herley-Kelley's Orduno No. 1, the lowest producing well (Del Valle zone) in the Ramona field. At 6,245–6,366 feet this well penetrated the Bering sand which is highly productive at the Del Valle field, but not explored yet at Ramona at the proper structural position.



RAMONA OIL FIELD

LOS ANGELES - VENTURA CO'S., CALIFORNIA

STRUCTURAL CONTOURS ON
TOP KERN PRODUCING ZONE

BY

LOYAL E. NELSON, PETROLEUM GEOLOGIST
LOS ANGELES, CALIF. FEBRUARY 28, 1946

FEET
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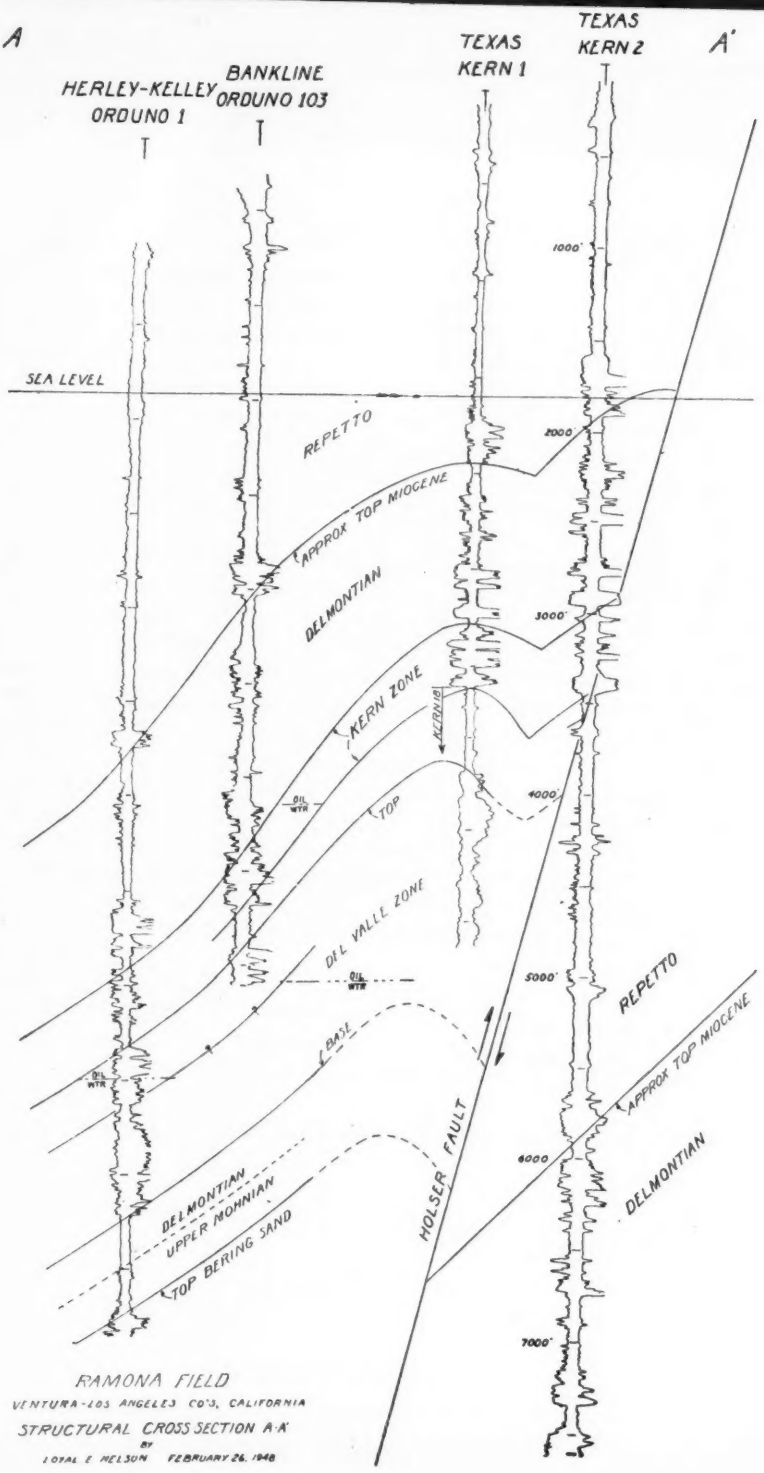
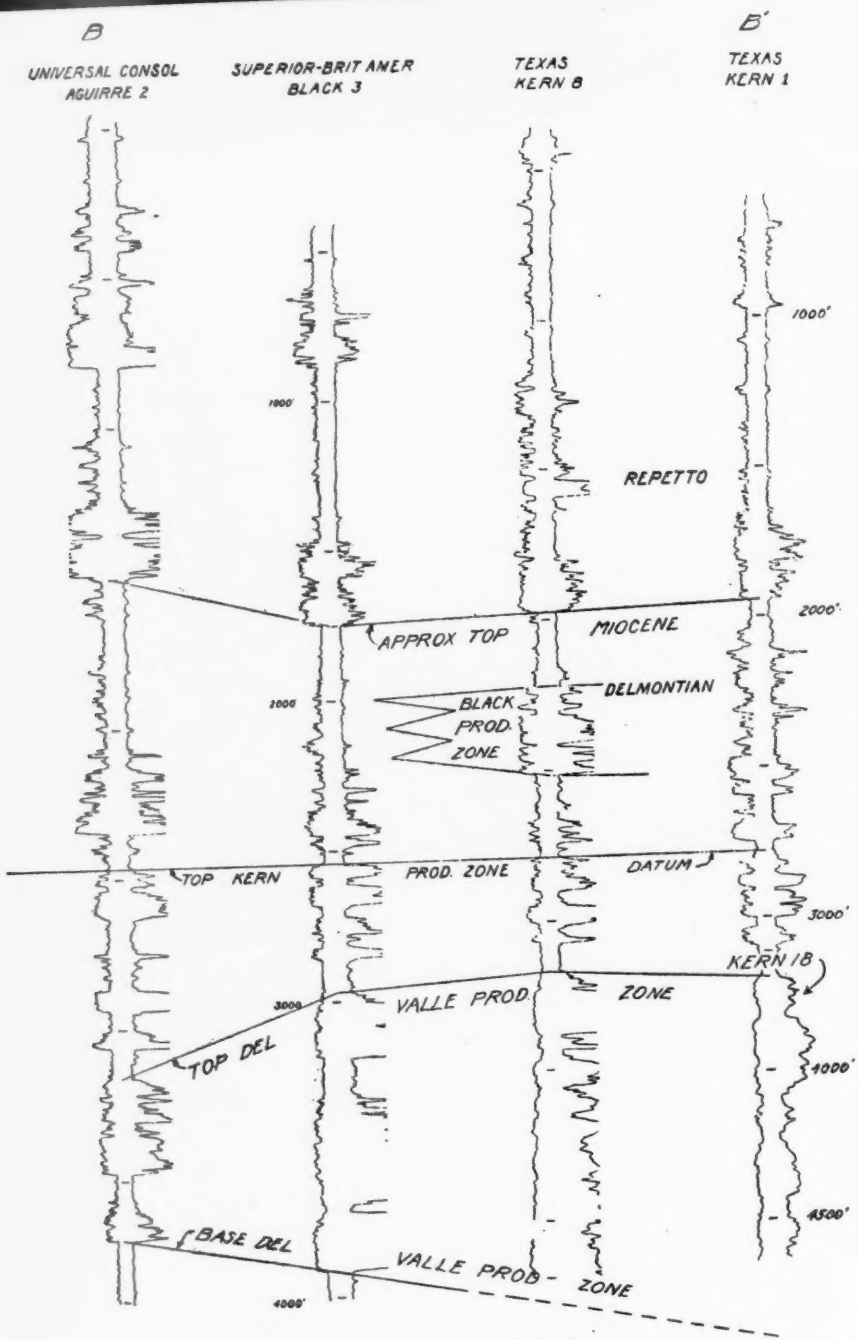
FIG. 1


A
HERLEY-KELLEY ORDUNO 1
BANKLINE ORDUNO 103
TEXAS KERN 1
TEXAS KERN 2
A'
SEA LEVEL
1000'
2000'
3000'
4000'
5000'
6000'
7000'
REPETTO
APPROX TOP MIOCENE
DELMONTIAN
KERN ZONE
ACEITUNO
TOP
OIL WTR
DEL VALLE ZONE
BASE
DELMONTIAN
UPPER MOHNIAN
TOP BERING SAND
HOLSER FAULT
REPETTO
APPROX TOP MIOCENE
DELMONTIAN
RAMONA FIELD
VENTURA-LOS ANGELES CO'S, CALIFORNIA
STRUCTURAL CROSS SECTION A-A'
BY
LOYAL E. NELSON FEBRUARY 26, 1948

2

FIG. 2



RAMONA FIELD

VENTURA-LOS ANGELES CO'S, CALIFORNIA

STRATIGRAPHIC SECTION B-B'

BY

LOYAL E NELSON FEBRUARY 26, 1948

FIG. 3

Particulars regarding each producing zone are as follows.

Black zone sand varies from fine-grained and well sorted to conglomeratic and ill sorted. Porosity and permeability values are fair to low. Well thicknesses range from 140 to 365 feet, of which 90–180 feet is sand at depths of 2,200–2,680 feet. Edge water is at 800–850 below sea-level. All wells are completed as pumpers with rates of 120–180 barrels per day of 24°–27° oil. The total productive area approximates 30 acres.

Kern zone sand is generally fine- to medium-grained and locally fine, coarse and poorly sorted. The total sand in 10–60-foot bodies ranges from 100 to 300 feet according to location of the well and the dip. Productive Kern sand is found at well depths of 2,000-4,000 feet. Edge water is estimated at approximately 2,200 feet below sea-level at the east end of the field and probably varies for different sands.

There were wide differences in initial completions of Kern-zone wells, varying from 25 to 196 barrels per day, flowing, in the first wells drilled. Later, the various operators included the Del Valle zone and made better wells with more sustained production. Kern zone oil is 20°–30° gravity.

The *Del Valle zone* consists of poorly sorted, fine to coarse sands and pebble to cobble conglomerates. Near the crest of the structure a shale body divides it into upper and lower members. The Del Valle is found productive at depths of 3,000–5,000 feet. The oil-water contact in the lower part of the Del Valle in the east half of the field is found at approximately 3,100 feet below sea-level. There is 140 feet of upper productive sand down to 3,620 feet below sea-level in Herley-Kelley's Orduno No. 1. Well thicknesses of productive Del Valle zone range from 300 to 1,400 feet, according to pinch-out conditions and dips.

All combination Kern and Del Valle wells initially pump 50–400 barrels per day of 18.5°–25° gravity oil. Approximately 270 acres are proved in the Kern and/or Del Valle.

There is a total of 64 wells in the field as of February, 1948, of which 9 are Black-zone completions. Three dry holes and non-commercial wells have been drilled since the discovery. The total production per day is approximately 5,000 barrels. Low gas-oil ratio is general. Proved reserves in all zones are estimated at 20 million barrels.

The field limits are not fully defined, especially on the west and southwest.

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REVIEWS AND NEW PUBLICATIONS

*Subjects indicated by asterisk are in the Association library, and are available, for loan, to members and associates.

TWO PROBLEMS OF MARINE GEOLOGY: ATOLLS AND CANYONS, BY PH. H. KUENEN

REVIEW BY K. O. EMERY[1]
Los Angeles, California

"Two Problems of Marine Geology: Atolls and Canyons," by Ph. H. Kuenen. *Verh. Koninklijke Nederlandsche Akad. van Wetenschappen, afd. Natuurkunde,* Tweedie Sectie, Deel 43, No. 3 (1947), pp. 1–69; 4 pls., 14 text figs. I. "The Borings on Maratoea Atoll and the Coral Reef Theory of Glacially Controlled Subsidence," pp. 5–36. II. "Submarine Canyons and Their Formation," pp. 37–69. Published by N. V. Noord-Hollandsche Uitgevers Maatschappij, Amsterdam, Holland. Paper. 7.125×10.25 inches. In English.

This paper by the well known Dutch marine geologist, Ph. H. Kuenen, is a review of the more important theories of the origin of atolls and of submarine canyons. The material was assembled by Kuenen for presentation as two of a series of lectures on marine geology at London University. The subjects are covered briefly but still thoroughly enough that the paper might well serve as a classroom reference for introducing the subjects to students if the journal were more readily available. It contains a number of well chosen illustrations.

Two recent borings on a low island in the lagoon of Maratoa Atoll, near Borneo, form the chief basis for his discussion of atolls. The borings passed through discontinuous coral limestones, which below 189 meters were interbedded with a fine-grained marl considered to be a lagoon-floor deposit. The bottom of the deeper hole, 429 meters, was still in calcareous material probably *in situ*. From physiographic evidence the shelf on which the reef grew was believed to lie at a depth of about 550 meters. The antecedent-platform theory appears to be eliminated because that depth is probably too great for organic growth upward from the bottom to the surface, and the building of a platform of fine-grained sediments is impractical because such sediments do not occur on present submarine highs. Kuenen also eliminated by general and local objections the two chief remaining theories: subsidence and glacial control. He proposed, however, that at least this atoll was formed by a combination of the two as "glacially controlled subsidence." In Tertiary time subsidence developed fringing reefs, barrier reefs, and atolls in turn as proposed by Darwin. During glacial time of low sea-level the cold water killed the corals in marginal seas, permitting waves to erode platforms and cliffs. In tropical areas where corals survived, the lowering of sea-level permitted both marine and subaerial processes to truncate the emerged rims of the former reefs. Some of the débris plus marine sediments rapidly filled any lagoons which remained below the new sea-level, thus accounting for the general similarity of depths in lagoons throughout most of the world. When sea-level later rose the reefs kept pace with it finding their best foundation over the truncated former reef rather than over the unstable inner sediments.

After presenting some of the chief characteristics of submarine canyons, Kuenen discussed their possible origins, drawing material largely from recent works of Johnson, Bucher, Daly, and especially Shepard. Like most marine geologists who have studied the

[1] Department of geology, University of Southern California. Review received, June 3, 1948.

problem, he considers that faulting is important only in weakening the rock for localizing later erosion, that spring sapping is out of the question because of the common lack of hydraulic head and the non-calcareous rock character of the walls of most canyons, and that Davis' hydraulic currents could not run down-slope because they consist of water less dense than that at depth. Tidal currents and currents due to tsunamis are also eliminated because of mechanical and geographical difficulties. Sub-aerial origin as usual is faced with a probably excessive glacial lowering of sea-level. Kuenen favors as the chief erosive agent turbidity currents on which he has written previously. Laboratory experiments which he conducted revealed that small scale turbidity (density) currents formed by introducing a sand suspension become concentrated in slight indentations of a slope and flow to the bottom of the slope. In nature, the suspension would have been obtained by wave erosion of a mud cover on the continental shelves, a cover which is not very extensive on present shelves. Some of the wall rock of the canyons may have been soft and fairly easily eroded by the turbidity currents, but the granite, lava, and fairly well cemented conglomerates in the walls of canyons off California are not so easily cut, even if they are weakened by faulting. The reviewer is not in full agreement with the turbidity current interpretation, but there seems to be near-fatal objections to every theory which has so far been proposed. Until more supporting facts are collected or a new theory which accords better with presently known facts is developed the subject remains an open and highly interesting field.

RECENT PUBLICATIONS

ALASKA

"Preliminary Report on the Geology and Petroleum Possibilities of the Iniskin Peninsula, Alaska," by C. E. Kirschner. *U. S. Geol. Survey* (June, 1948). Typewritten text, map, structure sections. Available for inspection in Rooms 4217 and 1033 (Library), Federal Works Agency Building, Washington, D. C.; Room 533, Postoffice and Court House, Los Angeles, California; Fairbanks and Juneau, Alaska.

ALGERIA AND TUNIS

* "Faciès, épaisser des sédiments et paléogéographie dans le Bas-Sahara pendant las temps secondaires" (Facies, Thickness of Sediments, and Paleogeography in the Lower Sahara in Secondary Time), by R. Laffitte. *Bull. Soc. Geol. France*, 5 ser., t. 17, Nos. 1, 2, 3 (Paris, 1947), pp. 213–16; 2 figs. French.

ARIZONA

* "Geomorphology and Structure of the West Kaibab Fault Zone and Kaibab Plateau, Arizona," by Arthur N. Strahler. *Bull. Geol. Soc. America*, Vol. 59, No. 6 (New York, June, 1948), pp. 513–40; 5 pls., 15 figs.

BRAZIL

* "Relatório de 1946" (Report for 1946). *Presidência da República Conselho Nacional do Petróleo* (Rio de Janeiro, 1948). Includes geological descriptions in states of Pará, Maranhão, Piaui, Sergipe, and Bahia. 6.25×9 inches. 308 pp., 28 figs., photographs. Paper cover. In Portuguese.

* "Le synclinal des Verrières (Jura) et la 'collapse structure' " (Verrières Syncline and the Collapse Structure), by G. Castany. *Ibid.*, pp. 199–208; 2 figs.

GENERAL

* *Fine-Grained Alluvial Deposits and Their Effects on Mississippi River Activity*, by Harold N. Fisk. 2 Vols. (1947). Vol. 1: 82 pp. (approx. 8×10.5 inches), 12 figs., frontis-

piece map in colors. Vol. 2: 74 pls. (approx. 15.5×21.5 inches), frontispiece map. Offset printed. Paper covers. War Department, Corps of Engineers, Mississippi River Commission, Waterways Experiment Station, Vicksburg, Mississippi. Price: per set, $2.50; per volume, $1.25.

* *A World Tour in Oil*, by Alfred M. Leeston. 35 pp. Brief, pertinent facts and figures about oil-producing countries. 6×9 inches. Paper cover. Alfred M. Leeston, 1000 Continental Building, Dallas, Texas. Price, $0.50.

* "Pleistocene of the Great Plains," by 13 authors. Introduction and Conclusions by E. H. Colbert. *Bull. Geol. Soc. America*, Vol. 59, No. 6 (New York, June, 1948), pp. 541–630; illus.

"Manual of Coastal Delineation from Aerial Photographs," by P. G. McCurdy. *U. S. Hydrogr. Office Pub. 592* (Washington, D. C., 1947). 143 pp., diagrams, illus. 12.25×9.25 inches. Price, $1.50. Review in *Amer. Geographical Review*, Vol. 38, No. 3 (New York, July, 1948), pp. 518–19.

* "Application of Secondary Recovery in the United States as Related to Emergency Oil Requirements," by Paul D. Torrey. *Oil World*, Vol. 41, No. 10 (Los Angeles, May, 1948), pp. 5–17.

* "Bibliography of Seismology, No. 2, Items 6505–6733, July to December, 1947," by W. G. Milne. *Pub. Dominion Observatory*, Vol. 14 (Canada Dept. Mines and Resources, Ottawa, 1948), pp. 23–52. Price, $0.25.

EASTERN MEDITERRANEAN

* "Problèmes de la géologie du Levant" (Geological Problems of the Levant), by L. Dubertret. *Bull. Soc. Géol. France*, 5 Ser., t. 17, Nos. 1, 2, 3 (Paris, 1947), pp. 1–32; 1 pl., 10 figs., 1 table. French.

* "Sur la limite septentrionale du Plateau-syrien" (Northern Limit of Syrian Plateau), by V. Stchépinsky. *Ibid.*, pp. 33–38; 1 fig. French.

ENGLAND

* "Marine Bands and Other Faunal Marker-Horizons in Relation to the Sedimentary Cycles of the Middle Coal Measures of Nottinghamshire and Derbyshire," by Wilfrid Edwards and C. J. Stubblefield. With an appendix on "Petrographical Descriptions of Two Cycles of Sedimentation from the Middle Coal Measures, Woodborough Borehole," by Kingsley Charles Dunham. *Quar. Jour. Geol. Soc. London*, Vol. 103, Pt. 4, No. 412 (Longmans, Green and Company, Ltd., 6–7 Clifford Street, London, W. i, May 11, 1948), pp. 209–60; 10 figs., 2 pls.

* "The Sequence and Structure of the Southern Portion of the East Crop of the South Wales Coalfield," by Leslie Rowsell Moore. *Ibid.*, pp. 261–300; 9 figs., 1 pl.

FLORIDA

* "Oil Possibilities in Florida," by Leigh S. McCaslin, Jr. *Oil and Gas Jour.*, Vol. 47, No. 9 (Tulsa, Oklahoma, July 1, 1948), pp. 64–70; 3 illus.

FRANCE

* "Une Grande région de faible résistance dans la partie médiane du Massif Central français" (A Large Region of Low Resistance in the Middle Part of the Central Massif of France), by P. Lapadu-Hargues. *Bull. Soc. Géol. France*, 5 Ser., t. 17, Nos. 1, 2, 3 (Paris, 1947), pp. 55–60; 1 fig. French.

Sequence in Layered Rocks, by Robert R. Shrock. 795 pp., illus. A Study of features and structures useful for determining top and bottom or order of succession in bedded and tabular bodies. McGraw-Hill Book Company, Inc., New York (1948). Price, $7.50.

GULF COAST

* "Basic Geology of the Gulf Coastal Area and the Continental Shelf," by J. Ben Carsey, *Oil and Gas Jour.*, Vol. 47, No. 8 (Tulsa, Oklahoma, June 24, 1948), pp. 246–51, 266–67; 5 figs.

IRAN

* "Saga of Southwestern Iran Is Paradox of Permeability," by H. S. Gibson. *Oil Forum* (New York, May, 1948), pp. 190–93; 3 figs.

KANSAS

* "Preliminary Notes on Lithologic Criteria for Identification and Subdivision of the Mississippian Rocks in Western Kansas," by Joseph R. Clair. *Kansas Geol. Soc. Pub.* (Wichita, June, 1948). 14 mimeog. pp. 8.5×11 inches. Folded map and generalized section in pocket. Copies may be purchased from Kansas Geological Society, 412 Union National Bank Building, Wichita 2, Kansas. Price, $1.00.

PACIFIC ISLANDS

"Aeromagnetic Map Showing Variations in Total Magnetic Intensity over Bikini Atoll." *U. S. Geol. Survey* in cooperation with *Naval Ordnance Laboratory* (1948). Map and text on open file in advance of publication. May be examined at Geological Survey Offices, Room 1033 (Library), Federal Works Agency Building, Washington, D. C., and 333 Federal Building, Honolulu, T. H.; and at Navy Department, office of Naval Research, Washington 25, D. C. Few available copies for distribution.

PERU

* "Promising Future for Peru's Oil," by J. E. Rassmuss. *World Petroleum*, Vol. 19, No. 6 (New York, June, 1948), pp. 40–42; 6 photographs.

ROCKY MOUNTAINS

* "Paradox Salt," by Glen M. Ruby. *Oil Reporter*, Vol. 5, No. 9 (Denver, Colorado, June 29, 1948), pp. 7, 26, 30; 1 fig.

WEST VIRGINIA

"The Clays of West Virginia," by John B. McCue, Homer A. Hoskins, L. W. Folsom, John P. Nolting, James H. C. Martens, A. J. Headlee, and Frederick W. Truscott. *West Virginia Geol. and Econ. Survey*, Vol. 18 (Morgantown, 1948). 250 pp. Analyses of 335 samples from 47 counties. Price, $1.50 (plus 2% tax in West Virginia).

"Analyses of West Virginia Brines," by Homer A. Hoskins. *West Virginia Geol. and Econ. Survey. Rept. Inves. 1.* Analyses of samples from wells drilled for oil and gas since publication of Volume 8 in 1937. Price, $0.25 (plus 2% tax in West Virginia).

"Composition and Properties of Petroleum in West Virginia," by A. J. W. Headlee, R. E. McClelland, and Homer A. Hoskins. *Ibid., Rept. Inves. 3.*

"Composition and Properties of Petroleum in West Virginia," by A. J. W. Headlee, R. E. McClelland, E. J. Ball, and Helen H. Hess. *Ibid., Rept. Inves. 3-A.* Results not included in *No. 3.*

WESTERN MEDITERRANEAN

* "Contribution á l'étude tectonique de la Méditerranée occidentale" (Tectonic Study of Western Mediterranean Region), by P. Russo. *Bull. Soc. Géol. France*, 5 Ser., t. 17, Nos. 1, 2, 3 (Paris, 1947), pp. 81–96; 4 figs. French.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 8 (AUGUST, 1948), PP. 1668-1681

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa 1, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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TECHNICAL PROGRAMS OF AFFILIATED SOCIETIES AND SECTIONS, SEASON OF 1947–1948

EASTERN SECTION, A.A.P.G., New York, N. Y.
Program chairman: Bruno O. Winkler, Standard-Vacuum Oil Company, Room 648, 26 Broadway.
Secretary: L. G. Weeks, Standard Oil Company (New Jersey), Room 2150, 30 Rockefeller Plaza.

Date	*Speaker*	*Subject*
Oct. 7, 1947	E. DeGolyer	Prospecting for Petroleum

Program chairman: Gail F. Moulton, Chase National Bank, 18 Pine Street.
Secretary: D. A. Greig, Standard Oil Company (New Jersey), Room 2150, 30 Rockefeller Plaza, New York City.

Date	*Speaker*	*Subject*
Dec. 10, 1947	F. Julius Fohs	Russian Oil Reserve Areas
Apr. 12, 1948	Clark Goodman	Radioactivity and Petroleum Geology

ABILENE GEOLOGICAL SOCIETY, Abilene, Texas.
Program chairman: James R. Day, Pan American Production Company, Alexander Building.
Secretary: J. C. Hunter, Mims Building.

Date	*Speaker*	*Subject*
Oct. 9, 1947	C. E. Dobbin	Coal and Oil Shale as Future Reserves of Petroleum
Nov. 13	K. Davison	General Problems and Aspects of Water Flooding
Dec. 11	Frank B. Counselman	Cambrian and Ordovician Oil Possibilities
Jan. 8, 1948	Study group	Review of Cross Section Geology of Big Bend
Feb. 12	John T. Lonsdale	Geology of Big Bend Region, Texas

Program chairman: A. E. Barnes, Lion Oil Company.
Secretary: Riley G. Maxwell, Box 1939.

Mar. 11	M. G. Cheney, Jr.	Observations in the Antartic
Apr. 20	Gordon Rittenhouse	Interpretative Petrology of Sedimentary Rocks
May 13	Stewart Noland	Geology of Eskota Pool, Fisher County, Texas

ALBERTA SOCIETY OF PETROLEUM GEOLOGISTS, Calgary, Alberta, Canada.
Program chairman: W. P. Hancock, Imperial Oil, Ltd., 339 Seventh Avenue, West.
Secretary: J. G. Gray, California Standard Company, 700 Lancaster Building.

Date	*Speaker*	*Subject*
Oct. 14, 1947	D. B. Layer	The "Lower Cretaceous" Beds of Alberta Plains
Oct. 14	L. M. Clark	Geology of Eastern Part of Fairholme Range in Vicinity of Bow River, Alberta
Nov. 27	J. Gleddie	Upper Cretaceous of Peace River Area of Alberta and Northeastern British Columbia
Nov. 27	P. S. Warren	Paleontological Zones of Devonian of Canadian Rocky Mountains and Plains Area
Jan. 12, 1948	Marland P. Billings	Orogeny in Appalachian Highlands of New England
Feb. 5	Conn Hage	Triassic Stratigraphy of Alberta and North Eastern British Columbia
Feb. 5	J. G. Gray	Stratigraphy of Princess Oil Field, Alberta
Feb. 26	C. E. Dobbin	Coal and Oil Shales as Future Petroleum Sources
Mar. 23	M. B. B. Crockford	Stratigraphy of Pale and Foremost Formations of Southern Alberta
Mar. 23	A. P. Keevil	Geology of Conrad and Taber Oil Fields, Alberta

APPALACHIAN GEOLOGICAL SOCIETY, Charleston, West Virginia.
Program chairman: J. E. Billingsley, West Virginia Gas Corporation.
Secretary: A. H. McClain, Owens, Libbey-Owens Gas Department.

Date	*Speaker*	*Subject*
Sept., 1947	Representative of West Virginia Public Service Commission	Shortage of Gas for West Virginia Domestic Consumers
Oct.	Louise B. Freeman	Knox Dolomite Exploration in Kentucky
Nov.	Ralph N. Thomas	Lithologic Characteristics in Big Six Sand in Kentucky
	Philip Jenkins	Practical Phases of Big Six Production
	David M. Young	Structural Relations of Big Six Sand
Jan., 1948	Ralph L. Miller	Rose Hill Oil Pool, Lee County, Virginia
Feb.	Representative of National Tube Company	Film showing manufacture of casing
	Representative of G. L. Cabot, Inc.	Film showing manufacture of carbon black
Mar.	N. J. Ehlers	Brine from West Virginia Rock Salt Strata
Apr.	R. N. Chennault	Application of Gas Lift for Small Wells
	C. C. Hogg	Oil Technology
	J. O. Bewley	Film "Application of Electricity to Production of Crude Oil"
	O. S. Hagerman	Film, "Eternal Flame"

ARDMORE GEOLOGICAL SOCIETY, Ardmore, Oklahoma.
Program chairman: Richard Kendall, California Company.
Secretary: Frank Millard, Schlumberger Well Surveying Corporation.

Date	*Speaker*	*Subject*
Oct. 2, 1947	E. DeGolyer	Prospecting for Petroleum
Nov. 19	R. C. Moore	Problems of Sedimentary Facies
Jan. 8, 1948	C. W. Tomlinson	Relationship between Well Spacing and Recovery with Proof of Cutler's Rule
Mar. 4	Robert Wheeler and R. M. Swesnik	Stratigraphic Convergence Problems in Oil-Finding
Apr. 1	Martin Kelsey	Studies in Fault Detection with the Reflection Seismograph
Apr. 5	C. E. Dobbin	
June, 18, 19	Ardmore field conference	Pennsylvanian System of Ardmore Basin
	M. G. Cheney	Correlation of Pennsylvanian Formations in Oklahoma and Texas

CORPUS CHRISTI GEOLOGICAL SOCIETY, Corpus Christi, Texas.
Program chairman: H. D. McCallum, Humble Oil and Refining Company.
Secretary: H. C. Cooke, c/o O. G. McClain, 224 Wilson Building.

Date	*Speaker*	*Subject*
Oct. 2, 1947	James G. White	Geology and Geography of Egypt
Oct. 16	Charles Ross	Deep Kelsey Production
Oct. 23	H. D. McCallum	Charlotte Field, Arkansas County
Oct. 30	C. E. Dobbin	Coal and Oil Shale as Future Reserves of Petroleum

Program chairman: Edwin A. Taegel, consulting geologist.

Nov. 13	O. G. McClain	Shallow Wilcox Fields in Southwest Texas
Nov. 20	Cecil R. Searcy	Engineering Knowledge Essential to Accurate Well Measurement
Nov. 25	Raymond C. Moore	Problems of Sedimentary Facies

Program chairman: Oscar M. Hudson, Phillips Petroleum Company.

Dec. 4	Courtesy of HOMCO	Movies showing operation of fishing tools, side-wall coring and directional drilling
Dec. 11	Edwin A. Taegel	Geological Reconnaissance, Southwestern Colorado, Northern New Mexico, Northeastern Arizona and Southeastern Utah

Program chairman: Dean F. Metts, Chicago Corporation, Box 1702.

Jan. 8, 1948	W. Armstrong Price	Origin of Pimple Mounds
Jan. 15	Dean F. Metts	Interesting Structures on Certain Louisiana Domes
Jan. 22	Hal Rachal, attorney	Pooling for Gas Production and Recycling Purposes
Jan. 29	John T. Lonsdale and Frank A. Herald	Discussion of Bureau of Economic Geology Affairs

Program chairman: Donald A. Ross, consulting geologist, Box 83.

Feb. 5	Edwin A. Taegel	Mexican Politics and Oil
Feb. 12	D. C. McCann	Electrical Logging and Auxiliary Schlumberger Services
Feb. 19	Charles I. Jennings	History of Discovery of Benedum Field in Upton County
Feb. 26	W. K. Denham	North Magnolia City Field

Program chairman: O. G. McClain, consulting, 224 Wilson Building

Mar. 4	O. G. McClain	Fulton Beach Field in Arkansas County
Mar. 11	D. C. McCann	Electrical Logging, with Particular Attention to Resistivity Curves
Mar. 18	John G. Campbell	Role of Chemist as Geologist's Assistant

Program chairman: C. C. Miller, Renwar Oil Corporation, 1801 Driscoll Building.

Apr. 1	W. J. Hilseweck	Recent Developments in West Texas and New Mexico
Apr. 8	H. G. Doll	Analysis and Principles of Self-Potential Log
Apr. 15	Travis Hicks	Geology of Viola Field, Nueces County
Apr. 22	John G. Caran	Core Analysis

Program chairman: J. D. Burke, Seaboard Oil Corporation.

May 6	Holland C. McCarver	Geology and Geophysics of Odem Oil Field, San Patricio County
May 13	W. H. Spice and T. L. Allen	Geology and Geophysics of Washburn Field, La Salle County, Texas
May 20	D. C. McCann	Electrical Logging and Related Services
May 27	Courtesy of The Texas Company	"New Frontier," An Arabian-American Oil Company film in technicolor and sound

Program chairman: George R. Pinkley, consulting geologist, Box 2305.

June 3	E. C. Sargent	Brayton Area, Agua Dulce Field
June 10	Edwin Jones	Acidization of Wilcox and Jackson Sands in Bee County, Texas

DALLAS GEOLOGICAL SOCIETY, Dallas, Texas.
Program chairman: John M. Clayton, Seaboard Oil Company, 1400 Continental Building.
Secretary: W. W. Newton, Geotechnical Corporation, Box 7166

Date	*Speaker*	*Subject*
Sept. 17, 1947	Paul Weaver	Geology of Denmark and Northern Germany
Oct. 15	C. E. Dobbin	Coal and Oil Shale as Future Reserves of Petroleum
Oct. 20	E. DeGolyer	Prospecting for Petroleum
Nov. 21	Raymond C. Moore	Problems of Sedimentary Facies
Nov. 26	L. L. Nettleton	Salt Domes of Mississippi
Dec. 17	Earle F. Taylor	Petroleum Geology and Development in Brazil

Program chairman: John T. Rouse, Magnolia Petroleum Company, Box 900.
Secretary: H. V. Tygrett, Atlantic Refining Company, Magnolia Building.

Jan. 20, 1948	Marland P. Billings	Orogeny in Appalachian Highlands of New England
Feb. 4	John T. Lonsdale	Geology of Big Bend Region, Texas
Mar. 10	Robert M. Swesnik	Stratigraphic Convergence Problems in Oil Finding
Mar. 17	Clark Goodman	Radioactivity and Petroleum Geology
Apr. 7	James W. Kisling, Jr.	Discussion of Regional Geology and General Geography of Eastern Ethiopia
Apr. 4	Paul Weaver	How Fast Do Salt Domes Grow?

Apr. 15	Gordon Rittenhouse	Interpretative Petrology of Sedimentary Rocks
May 11	J. W. Huddle	Devonian and Mississippian Paleogeography of Northeastern Arizona
June 2	Courtesy of Charles B. Carpenter	Sound movie, "A Story of Texas and Its Resources," prepared by U. S. Bureau of Mines and Texas Gulf Sulphur Company

EAST TEXAS GEOLOGICAL SOCIETY, Tyler, Texas.
Program chairman: L. F. Lees, Phillips Petroleum Company.
Secretary: W. E. Long, Geier-Jackson, Inc.

Date	*Speaker*	*Subject*
Oct. 16, 1947	C. E. Dobbin	Coal and Oil Shale as Future Reserves for Petroleum
Oct. 29	E. DeGolyer	History of Petroleum Exploration
Nov. 10	G. L. Turner	Black Hills, South Dakota
Dec. 2	R. C. Moore	Problems of Sedimentary Facies
Dec. 8	Phil Russell	Opelika Field, Henderson County, Texas
Jan. 12, 1948	G. J. Loetterle	Waskom Field, Harrison County, Texas
Jan. 19	J. S. Hudnall	History of East Texas Field
Feb. 2	R. T. Wade	Resistivity Departure Curves
Apr. 5	R. E. Bush	Interpretation of Gamma-Ray and Neutron Logs
Apr. 19	Gordon Rittenhouse	Interpretive Petrology of Sedimentary Rocks
May 24	Paul Weaver	How Salt Domes Grow
June 8	Dale H. Rowden	Review of Physical Properties of Reservoir Waters

FORT WORTH GEOLOGICAL SOCIETY, Fort Worth, Texas.
Program chairman: F. H. Schouten, Stanolind Oil and Gas Company, Box 1410.
Secretary: Millicent A. Renfro, Texas Pacific Coal and Oil Company, Box 2100.

Date	*Speaker*	*Subject*
Feb., 1948	Lee Parks	Geophysical History of Block 31, University Lands, Crane County, Texas
Mar.	R. B. Dowling	Radioactivity Well Logging
Apr.	E. G. Leonardon	Telluric Currents

HOUSTON GEOLOGICAL SOCIETY, Houston, Texas.
Program chairman: A. F. Childers, Jr., Gulf Oil Corporation.
Secretary: H. C. Ferguson, consultant, 935 Esperson Building.

Date	*Speaker*	*Subject*
Sept. 22, 1947	Frank Briggs	HOMCO's color and sound movie, "The Little Red Coupe"
Oct. 13	E. H. Rosaire	Economic Philosophy of the Professional Engineer and Scientist
Oct. 22	E. DeGolyer	Prospecting for Petroleum
Oct. 27	C. E. Dobbin	Coal and Oil Shales as Future Reserves for Petroleum
Nov. 10	John L. Terrell	Off-shore Drilling Operations
Nov. 24	Raymond C. Moore	Problems of Sedimentary Facies
Dec. 8	Warren L. Baker	Oil Has a Story That Must Be Told
Jan. 12, 1948	John T. Lonsdale	Geology of Big Bend Region of Texas
Jan. 21	M. C. Israelsky	An Oscillation Chart. A Possible Correlative Tool. Example—A Well in Lirete Field, Louisiana
Jan. 26	Marland P. Billings	Orogeny in Appalachian Highlands of New England
Feb. 9	Walter Osterhoudt	Seismograph Exploration of an Ancient Mississippian River Channel
Feb. 23	Martin G. Miller	Practical Aspects of Gas Cycling
Mar. 8	King Hubbert	Motion of Ground Water
Mar. 22	Arabian-American Oil Company's technicolor and sound movie—A New Frontier	
Mar. 26	Joint regional meeting of Houston Geological Society and Society of Exploration Geophysicists	
Mar. 26	A. I. Levorsen	Time of Oil Accumulation
Apr. 12	W. Armstrong Price	Pimple Mounds, Origin by Pocket Gophers. Distribution—Age—Significance in Quaternary Geology

Apr. 19	Gordon Rittenhouse	Interpretative Petrology of Sedimentary Rocks
May 10	J. W. Huddle	Devonian and Mississippian Paleogeography of North Eastern Arizona
May 13	Texas Agricultural and Mechanical College Annual Student Award meeting	
May 24	Earle F. Taylor	Petroleum Geology and Development in Brazil
June 14	Paul Weaver	Discussion of Field Trips in general, with technicolor movie of Ouachita Mountain field trip shown by John L. Ferguson

ILLINOIS GEOLOGICAL SOCIETY
Program chairman: C. E. Brehm, Box 368, Mount Vernon, Illinois.
Secretary: C. Doh, Schlumberger Well Surveying Corporation, Box 571, Matoon, Illinois.

Date	*Speaker*	*Subject*
Sept. 11, 1947	J. P. Smith	Influence of Pressure Maintenance in Dix Pool Area
Oct. 11	E. DeGolyer	Prospecting for Petroleum
Oct. 31	Dorsey Hager	Tectonics of North-Central United States
	L. E. Workman	New Albany Strata of Illinois
Jan. 14–15, 1948	Host to A.A.P.G. Eastern Interior regional meeting at St. Louis	
Feb. 6	Carl A. Bays	Electrical Well Logging in Illinois Basin
Mar. 19	Jack Campbell	Core Analysis in Illinois Basin
Apr. 6	Gordon Rittenhouse	Interpretative Petrology of Sedimentary Rocks
June 4	Stuart K. Clark	Structural Trends and Fault Systems in Eastern Interior Basin

INDIANA-KENTUCKY GEOLOGICAL SOCIETY, Evansville, Indiana.
Secretary: P. L. Keller, Great Lakes Carbon Company.

Date	*Speaker*	*Subject*
Sept. 19, 1947	J. P. Smith	Influence of Pressure Maintenance in Dix Pool Area
Oct. 11	E. DeGolyer	Prospecting for Petroleum
Nov. 14	G. T. Wickwire	Effects of Waste Acids on Limestones
Jan. 14, 15, 1948	Host to Eastern Interior regional meeting, St. Louis	
Feb. 21	Louise B. Freeman	Report on Deep Drilling in Kentucky
Mar. 13	R. B. Downing	Introduction to Radioactivity Well Logging

Secretary: E. J. Combs, Sun Oil Company, Box 717

May 6	Gordon Rittenhouse	Interpretative Petrology of Sedimentary Rocks

KANSAS GEOLOGICAL SOCIETY, Wichita, Kansas.
Program chairman: E. A. Huffman, c/o J. M. Huber Corporation, 302 Petroleum Building.
Secretary: Shirley E. Lenderman, Stanolind Oil and Gas Company.

Date	*Speaker*	*Subject*
Sept. 25, 1947	C. E. Dobbin	Coal and Oil Shale as Future Reserve of Petroleum
Nov. 11	Wallace Lee	Development of Regional Structure in Eastern Kansas
Jan. 13, 1948	Raymond C. Moore	Problems of Sedimentary Facies
Feb. 10	L. R. Laudon	Geology by Air
Mar. 25	Robert G. Hamilton	Interpretation of Electric Logs
Apr. 9	C. A. Moore	Morrow Series of Northeastern Oklahoma
Apr. 13	C. B. Collins	Development of Law of Oil and Gas
May 11	J. R. Clair	Lithologic Criteria for Subdivision of Mississippian Formation for Western Kansas
Mar., Apr., May	L. G. Chombart	Interpretation of Electric Logs (Series of 8 lectures presented with illustrations and slides of electric logs)

MICHIGAN GEOLOGICAL SOCIETY
Program chairman: W. A. Kelly, Michigan State College, East Lansing
Secretary: H. J. Hardenburg, Michigan Geological Survey, Lansing.

Date	*Speaker*	*Subject*
Oct. 14,1947	W. E. Shoenick	Field Recovery of Oil
Nov. 11	R. C. Moore	Problems of Sedimentary Facies
Dec. 17	George V. Cohee	Lower and Middle Silurian Rocks of Michigan
	Rex P. Grant	Recent Developments in Western Michigan

Jan. 20, 1948	Deane E. Kilbourne	Origin of Howell Structure
	H. W. Wolcott	Geology and Producing Characteristics of Coldwater Gas and Oil Field
Feb. 12	H. R. Wanless	Cyclical Sedimentation in Marine Deposits
Mar. 17	Social meeting	
Apr. 20	Joint meeting with Michigan Academy of Science	
May 12	Election of officers. Presentation of outline of June field trip	
June 17–21	Field trip	

MISSISSIPPI GEOLOGICAL SOCIETY, Jackson, Mississippi.
Program chairman: B. F. Murphy, Amerada Petroleum Corporation, Box 2086.
Secretary: Carl F. Grubb, Superior Oil Company.

Date	*Speaker*	*Subject*
Oct. 20, 1947	C. E. Dobbin	Coal and Oil Shale Deposits in United States
Oct. 27	E. DeGolyer	Prospecting for Petroleum
Dec. 1	R. C. Moore	Problems of Sedimentary Facies
Jan. 8, 1948	J. L. Terrell	Color Movies of Magnolia Well Drilled in Gulf of Mexico
Jan. 27	M. P. Billings	Orogeny in Appalachian Highlands of New England
Feb. 19	L. L. Nettleton	Mississippi Salt Domes
Mar. 4	A. Claudet	Quantitative Interpretation of Electric Logs
Mar. 23	A. I. Levorsen	Time of Oil Accumulation
Apr. 9	Gordon Rittenhouse	Interpretative Petrology of Sedimentary Books
Apr. 22	Dale H. Rowden	Physical Properties of Reservoir Waters
May 14	John W. Huddle	Devonian and Mississippian Paleogeography of Northeastern Arizona
May 28	Tom McGlothlin	Sedimentary Cycles in Gulf Cretaceous of Southern United States

NORTH TEXAS GEOLOGICAL SOCIETY, Wichita Falls, Texas.
Program chairman: L. T. Tier, Anderson-Prichard Oil Corporation.
Secretary: J. W. McDonald, Shell Oil Company.

Date	*Speaker*	*Subject*
Nov. 4, 1947	E. DeGolyer	Prospecting for Petroleum
Jan. 23, 1948	M. P. Billings	Orogeny in Appalachian Highlands of New England
Feb. 11	John T. Lonsdale	Big Bend Country of Southwest Texas
Mar. 11	Clark Goodman	Radioactivity and Petroleum Geology
Apr. 15	Gordon Rittenhouse	Interpretative Petrology of Sedimentary Rocks
May 13	J. W. Huddle	Devonian and Mississippian Paleogeography of Northeastern Arizona

OKLAHOMA CITY GEOLOGICAL SOCIETY, Oklahoma City.
Program chairman: Ben F. Baldwin, Stanolind Oil and Gas Company, Box 5564.
Secretary: L. R. Wilson, Carter Oil Company, 1300 Apco Tower.

Date	*Speaker*	*Subject*
June 12, 1947	Robert Hamilton	History, Use and Application of Schlumberger Dip Meter Instrument
July 10	Jack Abernathy	Problems of Deep Drilling
July 24	E. G. Dahlgren	Underground Natural Gas Reservoirs and Storage
Aug. 14	James D. Pate	Geology of Cotton County, Oklahoma
Sept. 25	Carl A. Moore	Electronic Microscope
Oct. 2	E. DeGolyer	Prospecting for Petroleum
Oct. 9	L. H. Humphrey	Prospecting for Petroleum (Sound and color movie, sponsored by Shell Oil Company)
Oct. 23	John M. Parker	Prospecting for Petroleum in Northwest Territories
Nov. 14	L. B. Tromba	Seismograph Exploration as a Tool to a Geologist
Dec. 2	J. G. Bartram	Jurassic of Colorado
Dec. 11	Erwin L. Selk	Problems of "Mayes" in Oklahoma
Feb. 12, 1948	R. M. Swesnik	Stratigraphic Convergence Problems in Oil Finding
Feb. 26	John T. Rouse	Challenges to American Association of Petroleum Geology Research
Mar. 9	Clark Goodman	Radioactivity and Petroleum

Mar. 25	Richard P. Swirczynski	Geology of Northwest Sulphur Pool, Oklahoma
Apr. 13	Gordon Rittenhouse	Interpretative Petrology of Sedimentary Rocks
Apr. 19	W. H. Twenhofel	Marine Cycle on Submerged and Submerging Coasts
May 13	K. Arbenz	Geology of Switzerland
May 18	Hugh D. Miser	Some Notes on Geology and Geologists, 1907–1947

PACIFIC SECTION, A.A.P.G., Los Angeles, California.
Program chairman: James C. Kimble, General Petroleum Corporation, 1033 Higgins Building.
Secretary: Clifton W. Johnson, Richfield Oil Corporation, 555 South Flower Street.

Nov. 6–7, 1947	Symposium	Occurrence and Production of Oil from Fractured Rocks in California, and other papers on program of annual meeting of Section at Pasadena

Program chairman: Clifton W. Johnson.
Secretary: P. H. Gardett, General Petroleum Corporation.

Jan. 8, 1948	Earl B. Noble	Oil Exploration in Northern Alaska
Feb. 5	Irving Smith	Tidelands as Affected by United States Supreme Court Decision
Mar. 4	Robert P. Sharp	Geologic Exploration in St. Elias Range, Canada

Other speakers have come from the Distinguished Lecture group. Other activities of the Pacific Section A.A.P.G. include a monthly meeting in Los Angeles of the Geologic Forum and similar meetings in Bakersfield and Santa Barbara. Papers presented at these meetings are extremely informal and deal with: (1) current development or new discoveries in the California oil-producing areas: (2) unusual or interesting experiences of an individual, for example, a man who has had foreign duty or worked in an entirely different province may relate his experience; (3) new tools that are of interest to the geologist. At the request of the majority of authors contacted, an itemized list of these papers is not included here. It is felt that this activity is more in the class of a discussion or study group.

PANHANDLE GEOLOGICAL SOCIETY, Amarillo, Texas.
Program chairman: R. J. Gutru, Cities Service Oil Company, Box 350.
Secretary: Fred S. Alexander, Standard Oil Company of Texas, Box 2087.

Date	*Speaker*	*Subject*
Jan. 21, 1948	Film by Humble	Trouble Lurks Below
Feb. 4	J. E. Gibson	Baroid Drilling Model
Mar. 17	Fred Neslage	West Pampa Repressure Project
Apr. 21	Richard E. Giles	Hydrocarbon Well Logging and Its Application
May 8	J. W. Huddle	Devonian and Mississippian Paleogeography of Northeast Arizona
May 19	John C. Maher	Pre-Pennsylvanian Geology of Hugoton Embayment

PITTSBURGH GEOLOGICAL SOCIETY, Pittsburgh, Pennsylvania.
Program chairman: C. F. Bassett, Gulf Oil Corporation, Box 1166.
Secretary: David K. Kirk, Gulf Research Development Company, Box 2038.

Date	*Speaker*	*Subject*
Oct. 8, 1947	E. DeGolyer	Prospecting for Petroleum
Oct. 27	W. H. Twenhofel	Some Sedimentational Consequences of Environmental Conditions with Reference to Development of Deposits of Sand and Gravel
Nov. 21	Laurence Brundall	Photogeology Applied to Oil and Gas Prospecting
Jan. 5, 1948	Marland P. Billings	Orogeny in Appalachian Highlands of New England
Feb. 10	R. C. Stephenson	Uranium-Vanadium Deposits of Colorado Plateau Area
Mar. 5	LeRoy Kay	Fossil Vertebrates as Indices to Age of Rocks
Apr. 1	Gordon Rittenhouse	Interpretative Petrology of Sedimentary Rocks
May 12	K. C. Heald	Geologists and Geology

SHAWNEE GEOLOGICAL SOCIETY, Shawnee, Oklahoma.
Program chairman: Fred J. Smith, Sinclair Prairie Oil Company, Box 991.
Secretary: Miss Marcelle Mousley, Atlantic Refining Company, Box 169.

Date	*Speaker*	*Subject*
Oct. 16, 1947	John G. Bartram	Geology and Oil Possibilities of Jurassic of Colorado
Nov. 6	R. B. Downing	Radioactivity Logging
Nov. 18	R. C. Moore	Problems of Sedimentary Facies
Dec. 4	L. H. Lukert	Lower Permian and Pennsylvanian Correlations in North-Central Oklahoma
Jan. 15, 1948	J. D. Pate	Petroleum Geology of Cotton County, Oklahoma
Feb. 19	John Rupnick	Elementary Talk on Geophysics
Mar. 4	M. C. Oakes	Field Work on State Geological Map
Mar. 18	C. W. Tomlinson	Proof of Cutler's Rule
Apr. 15	H. D. Miser	Some Notes on Geology and Geologists from 1907 to 1947
May 6	Robert G. Hamilton	General Interpretation of Electric Well Logs

SHREVEPORT GEOLOGICAL SOCIETY, Shreveport, Louisiana
Program chairman: E. W. Scott, Union Oil Company of California, 635 Ricou-Brewster Building.
Secretary: R. T. Chapman, Stanolind Oil and Gas Company, Box 1092.

Date	*Speaker*	*Subject*
Sept. 22, 1947	John Terrell	Off-Shore Drilling Operations
Oct. 17	C. E. Dobbin	Coal and Oil Shale
Oct. 28	E. DeGolyer	Prospecting for Petroleum
Nov. 11	John Murrell	Our Oil Reserves
Dec. 15	L. L. Nettleton	Geophysical Surveys
Feb. 2	George Harris	Wesson Field
Mar. 4	M. King Hubbert	Mechanical Basis for Faulting and Related Geologic Structures
Mar. 18	Clark Goodman	Radioactivity and Petroleum Geology
Mar. 19	Fred M. Bullard	Paricutin
Apr. 19	Warren L. Baker	Oil Has a Story That Must Be Told
May 11	H. G. Doll	S.P. Log: Theoretical Analysis and Principles of Interpretation
May 22	Paul Weaver	Rate of Growth of Salt Domes
June 7	James W. Kisling	Discussion of Regional Geology and General Geography of Eastern Ethiopia

SOUTHEASTERN GEOLOGICAL SOCIETY, Tallahassee, Florida.
Program chairman: James L. Martin, Jr., Sinclair Prairie Oil Company, Box 776.
Secretary: Eleanor T. Caldwell, Humble Oil and Refining Company, Box 506.

Date	*Speaker*	*Subject*
Oct. 25, 1947	E. DeGolyer	Prospecting for Petroleum
Nov. 28	Raymond C. Moore	Problems of Sedimentary Facies
Jan. 29, 1948	Marland P. Billings	Orogeny in Appalachian Highlands of New England
Mar. 19	Clark Goodman	Radioactivity and Petroleum Geology
Apr. 8	Eric Boissonnas	Geophysical Prospecting by Telluric Currents
June 4	H. Wayne Hoylman	Airborne Magnetometer

SOUTH LOUISIANA GEOLOGICAL SOCIETY, Lake Charles, Louisiana.
Program chairman: Roy A. Payne, Gulf Refining Company.
Secretary: W. Farrin Hoover, Stanolind Oil and Gas Company.

Date	*Speaker*	*Subject*
Oct. 8, 1947	Paul Weaver	Salt Domes of Germany, Denmark, Norway, and Sweden
Oct. 23	E. DeGolyer	History of Exploration for Petroleum
Nov. 26	R. C. Moore	Problems of Sedimentary Facies
Dec. 9	L. Hargrove	Educational film, "Prospecting for Petroleum," and the Shell Research Program

Program chairman: E. M. Ross, Jr. Amerada Petroleum Corporation, Lafayette.
Secretary: H. L. Tipsword, Magnolia Petroleum Corporation, Lake Charles.

Date	*Speaker*	*Subject*
Jan. 21, 1948	J. Adams	Colored movie, "Trouble Lurks Below," showing Humble's operations in successfully killing a well which had blown wild and caught fire off the coast of Corpus Christi
Feb. 24	Robert Suggs	Shoran Surveying
Mar. 30	Walter Osterhoudt	Seismograph Exploration of Ancient Mississippi River Channel
Apr. 15	J. W. Kisling, Jr.	Travelogue and movies describing travels in Africa
May 20	L. Nettleton	Mississippi Salt Domes

TULSA GEOLOGICAL SOCIETY, Tulsa, Oklahoma.
Program chairman: Jerry E. Upp, Amerada Petroleum Corporation, Box 2040.
Secretary: V. L. Frost, Ohio Oil Company, Thompson Building.

Date	*Speaker*	*Subject*
Oct. 3, 1947	E. DeGolyer	Prospecting for Petroleum
Oct. 20	James D. Pate	Geology and Oil Resources of Cotton County, Oklahoma
Nov. 3	C. O. Willson	Seeking Oil in Arctic Alaska
Nov. 17	Raymond C. Moore	Stratigraphic Classification in Relation to Facies
Dec. 1	John M. Parker	Prospecting for Oil in Northwest Territories, Canada
Dec. 15	Robert J. Hamilton	Practical Interpretation of Electric Logs
Jan. 5, 1948	H. A. Koch	Applications of Electric Pilot in Selective Acidizing and Permeability Surveys
Jan. 19	Marland P. Billings	Orogeny in Appalachian Highlands of New England
Feb. 9	C. T. Jones	Geology of Rift Valleys of Eastern Africa
Feb. 23	R. M. Swesnik and Robert R. Wheeler	Stratigraphic Convergence Problems in Oil Finding
Mar. 8	Clark Goodman	Radioactivity and Petroleum Geology
Mar. 22	A. I. Levorsen	Time of Oil Accumulation
Apr. 9	Jimmie C. Smith	Garden Grove Pool, Okfuskee and Lincoln Counties, Oklahoma
Apr. 12	Gordon Rittenhouse	Interpretative Petrology of Sedimentary Rocks
Apr. 19	Hugh D. Miser	Some Notes on Geology and Geologists, 1907–1947
Apr. 23	J. W. Huddle	Devonian and Mississippian Paleogeography of Northeastern Arizona
May 17	Carl A. Moore	Morrow Formation of Northeastern Oklahoma
May 28	W. Baxter Boyd and E. C. Parker	Northeast Butterly Field, Garvin County, Oklahoma

WEST TEXAS GEOLOGICAL SOCIETY, Midland.
Program chairman: Berte R. Haigh, University of Texas Lands.
Secretary: Clyde W. Turner, Gulf Oil Corporation.

Date	*Speaker*	*Subject*
Oct. 8, 1947	C. E. Dobbin	Coal and Oil Shale as Future Reserves of Petroleum
Nov. 13	E. DeGolyer	Prospecting for Petroleum
Dec. 5	Raymond C. Moore	Problems of Sedimentary Facies
Jan. 19, 1948	John A. Frost	Canyon County
Mar. 27	A. I. Levorsen	Time of Oil Accumulation
May 7	J. W. Huddle	Devonian and Mississippian Paleogeography of Northeastern Arizona
June 29	W. L. Broadhurst	Technique of Evaluating Our Ground-Water Resources

WYOMING GEOLOGICAL ASSOCIATION, Casper, Wyoming
Program chairman: W. Stanley Knouse, Tide Water Associated Oil Company, Box 1708.
Secretary: H. E. Summerford, Chemical Laboratories, Inc., Box 279.

Date	*Speaker*	*Subject*
Oct. 17, 1947	R. McMillan *et al.*	Photogeology and Its Application to Oil Exploration
Nov. 11	E. DeGolyer	Prospecting for Petroleum

Dec. 12	Raymond C. Moore	Problems of Sedimentary Facies
Jan. 30, 1948	George Downs	Some Geological Aspects of Wind River Basin
Feb. 27	Ray Thompson	Oil Exploration in Northern Alaska
Mar. 3	E. G. Leonardon	Exploration by Telluric Currents
Mar. 8	J. Crawford G. Steele	Relationship of Chemistry to Petroleum Industry Possibilities of Chemical Industry in Wyoming
Mar. 22	Harry Tourtelot	Tertiary Stratigraphy of Wind River Basin
Apr. 16	J. W. Huddle	Devonian and Mississippian Paleogeography of Northeastern Arizona

AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE CENTENARY, WASHINGTON, D. C., SEPTEMBER 13–17, 1948

"One World of Science" will be the keynote of the American Association for the Advancement of Science Centenary to be held in Washington, D. C., September 13–17. The daily schedule of activities during the celebration has been planned so that members and guests will have every opportunity to visit the great cultural displays, monuments, and research centers in and near the District. The scientific sessions will be held during the morning and evening, leaving the afternoons open for sightseeing and formal tours.

The morning programs will consist of technical symposia on scientific problems of great importance. Each symposium will consist of three papers presented by representatives of different fields of specialization. At the close of each session there will be comments by a panel of discussants drawn from among distinguished authorities.

MONDAY EVENING

The President of the United States will address the opening session on Monday evening, September 13, in Constitution Hall. The second major address of the evening will be delivered by the retiring president of the Association, Harlow Shapley, director of Harvard College Observatory. Upon adjournment, members and registered guests are cordially invited to attend the Diplomatic Reception in tribute to "One World of Science" which will be held in the Pan American Union Building adjacent to Constitution Hall. The other evening sessions will consist of semi-popular lectures by eminent scientists which will be open to members, their guests, and to the general public.

TUESDAY MORNING, SEPTEMBER 14

World's Natural Resources: G. E. Hutchinson, Yale University; T. S. Lovering, U. S. Geological Survey; Stanley A. Cain, Cranbrook Institute. Kirtley F. Mather, presiding, Harvard University.

Human Individuality: L. L. Thurstone, University of Chicago; Leslie A. White, University of Michigan; L. H. Snyder, University of Oklahoma. Lyle Lanier, presiding, New York University.

Genes and Cytoplasm: Tracy M. Sonneborn, Indiana University; Curt Stern, University of California at Berkeley; David Bonner, Yale University. H. J. Muller, presiding, Indiana University.

Housing: Bryn J. Hovde, Director, New School of Social Research, New York, N. Y.; Livingston Houston, Rensselaer Polytechnic Institute, Troy, N. Y.; Coleman Woodbury, University of Wisconsin. Douglas E. Parsons, presiding, National Bureau of Standards.

High Polymers: Hubert M. James, Purdue University; R. M. Fouss, Yale University; B. J. W. Debye, Cornell University. E. J. Cohn, presiding, Harvard University.

TUESDAY EVENING

Technics and the Future of Western Civilization: Lewis Mumford, Amenia, New York.

How and Why Birds Migrate: Ernst Mayr, American Museum of Natural History, New York.

Science and the Control of Human Populations: Warren S. Thompson, Scripps Foundation of Oceanography, La Jolla, California.

America's Town Meeting of the Air: Radio Forum: "What Hope for Man?" Karl T. Compton, Massachusetts Institute of Technology; Robert Hutchins, The University of Chicago; Fairfield Osborn, New York Zoological Society; Harlow Shapley, Harvard University.

WEDNESDAY MORNING, SEPTEMBER 15

Sources of Energy: Farrington Daniels, University of Wisconsin; M. King Hubbert, Shell Oil Company, Houston; Eugene P. Wigner, Palmer Physical Laboratory, Princeton University. Roger Adams, presiding, University of Illinois.

Interactions of Radiations and Matter: Willis E. Lamb, Columbia University; C. M. G. Lattes, University of California at Berkeley; John A. Wheeler, Princeton University. Isidor I. Rabi, presiding, 450 Riverside Drive, New York, New York

The Upper Atmosphere: Donald H. Menzel, Harvard University; Marcel Schein, The University of Chicago; H. C. Willett, Massachusetts Institute of Technology. F. W. Reichelderfer, presiding, Weather Bureau, Washington.

World's Health Problems: Ernest C. Faust, School of Medicine, Tulane University; Leonard A. Scheele, U. S. Public Health Service; Stafford L. Warren, University of California at Los Angeles. Thomas Parran, presiding, U. S. Public Health Service.

Educability: Ralph W. Tyler, University of Chicago; Talcott Parsons, Harvard University, Arnold Gesell, Yale University. Fernandus Payne, presiding, Indiana University.

WEDNESDAY EVENING

Oxygen Isotopes in Nature and in the Laboratory: Harold C. Urey, Institute for Nuclear Studies, University of Chicago, Chicago.

Psychiatry: Kenneth E. Appel, University of Pennsylvania, Philadelphia.

A Theory of Nerve Impulse: Arturo Rosenblueth, Instituto N. de Cardiologia, Mexico City, Mexico.

Wood in the Modern World: J. Alfred Hall, 423 U. S. Court House, Portland, Oregon.

Science and UNESCO: Detlev W. Bronk, National Research Council, Washington, D. C.

THURSDAY MORNING, SEPTEMBER 16

Sciences of Society: Samuel A. Stouffer, Harvard University; Alfred L. Kroeber, University of California at Berkeley; Kenneth E. Boulding, Iowa State College. Virginia C. Gildersleeve, presiding, 3007 Broadway, New York, New York.

Problems of the Ocean: Daniel Merriman, Yale University; Richard H. Fleming, United States Hydrographic Office; Carl Eckart, Scripps Institution of Oceanography, La Jolla, California. Vice Admiral Harold G. Bowen, presiding, Office of Naval Research.

Food and Nutrition: William A. Albrecht, University of Missouri; C. A. Elvehjem, University of Wisconsin; Margaret Mead, American Museum of Natural History, New York, New York. Anton J. Carlson, presiding, University of Chicago.

Waves and Rhythms: Hudson Hoagland, Worcester Foundation for Experimental Biology, 222 Maple Avenue, Shrewsbury, Massachusetts; V. O. Knudsen, University of California at Los Angeles; James B. Macelwane, Saint Louis University. W. S. G. Swann, presiding, Bartol Foundation, Swarthmore.

THURSDAY EVENING

Giant Machines for Research: Electron Microscope; James Hillier, R. C. A. Laboratories, Princeton. Giant Atom Smashers; Leland L. Haworth, Brookhaven National Laboratories, Upton, N. Y.

The Human Frontier: Roger J. Williams, University of Texas, Austin.

One World of Physics: A.A.A.S.-Sigma Xi Lecture; Carl D. Anderson, California Institute of Technology, Pasadena.

Medical Research: Andrew C. Ivy, University of Illinois, Chicago.

Advance registration and information may be obtained from A.A.A.S. Administrative Offices, 1515 Massachusetts Avenue, N. W., Washington 5, D. C.

HIGHLIGHTS ON 1947 DEVELOPMENT IN FOREIGN PETROLEUM FIELDS

CORRECTIONS[1]

L. G. WEEKS[2]
New York, N. Y.

Attention should be called to certain errors and omissions in data furnished me, which appeared in my paper on 1947 Developments in Foreign Fields, published in the June, 1948, issue of the *Bulletin*.

PANAMA

Page 1105.—We reported that the dry hole completed in 1937 by Sinclair Panama Oil Corporation on Colon Island (Panama) was a seismograph location. While a seismograph survey had been made of the island in 1937, credit for the location should be given entirely to surface geology.

VENEZUELA

Pages 1111–1115.—We neglected to report that a new-pool discovery was made in the State of Guarico (Venezuela) by the Las Mercedes Company (Texas-Caracas) with the completion of Palacio No. 4 for an initial potential of 660 bbls./day of 30.6° A.P.I. oil through a $\frac{3}{4}$-inch choke. Also unreported, the same company made the following gas discoveries in the State of Guarico in 1947:

Grico	No. 4	4,206 MCF
Punzon	No. 1	4,640 MCF
Valle	No. 1	4,260 MCF

Page 1113.—After noting the important Cretaceous discovery in Richmond (S.O. California) Zulia 26–1, about 120 kilometers southwest of Maracaibo, we omitted to mention a commercial discovery of heavy oil in Richmond well, Zulia 7–1. This discovery, said to be from the Eocene, is also on the west side of the lake about 45 kilometers southwest of Maracaibo.

COLOMBIA

Page 1117.—In the table, under *Sinu Basin* (Colombia), Tablon No. 1 wildcat well of Texas-Socony is reported to have had a large gas show and abandoned. This well was not abandoned but was actually completed for 13,000 MCF of gas.

Page 1117.—In the same table, San Andres well No. 1 is listed as having been drilled by Cities Service, Phillips, and Sinclair. The operators interested in the drilling of this well were Sinclair, Cities Service, and Richfield.

[1] Original paper published in *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 32, No. 6 (June, 1948), pp. 1093–1160. Corrections received, July 12, 1948.

[2] Chief research geologist, Standard Oil Company (New Jersey).

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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AT HOME AND ABROAD

NEWS OF THE PROFESSION

The Shawnee Geological Society, Shawnee, Oklahoma, has elected officers for the new administrative year: president, FRED J. SMITH, Sinclair Prairie Oil Company, Box 991; vice-president, DOYLE M. BURKE, The Texas Company, Box 1007; secretary-treasurer, MARCELLE MOUSLEY, Atlantic Refining Company, Box 169.

ANTHONY FOLGER, consulting geologist, has been representative of DeGolyer and MacNaughton in Mexico City in connection with their contract with Pemex (Petroleos Mexicasos). Folger was geologist with the Gulf Oil Corporation in Wichita, Kansas, from 1923 to 1942.

HEINZ A. LOWENSTAM, associate geologist on the Illinois Geological Survey, was granted a leave-of-absence, effective on June 15, to join the staff of the department of geology at the University of Chicago.

WALTER W. MORRIS is production superintendent for J. F. Smith, Shawnee, Oklahoma. Morris was in the oil and gas department of the Eagle Picher Mining and Smelting Company of Henryetta, Oklahoma, for 25 years.

DAN E. FERAY received the degree of Doctor of Philosophy in geology at the University of Wisconsin, June, 1948; he is now located at the Bureau of Economic Geology, Austin, Texas.

W. PHILIP COX has resigned from the producing department, Socony-Vacuum Oil Company, Inc., New York, and opened offices in the Shoreham Building, Washington, D. C., as a petroleum engineering and government relations consultant to oil operators and equipment manufacturers.

D. H. ELLIOTT has been transferred from the Tropical Oil Company, Barranquilla, Colombia, to the Creole Petroleum Corporation, Caracas, Venezuela. He is engaged in surface geological mapping in the field.

LEWIS H. BOYD has left the Western Geophysical Company, Tulsa, Oklahoma, to accept a position as gravity computer with the Richmond Exploration Company in Maracaibo, Venezuela.

WADE H. HADLEY, JR., recently with the Pure Oil Company, New Orleans, Louisiana, is with the Mene Grande Oil Company, Caracas, Venezuela.

JOE W. LUCKETT, JR., graduated from the Texas Technological College in June, and reported for work with the Pure Oil Company at Midland, Texas.

DON L. FRIZZELL has resigned from The University of Texas, and has accepted a post as associate professor of geology at the Missouri School of Mines, Rolla, Missouri.

E. H. SOPER has changed his company affiliations from The Texas Company, Shelby, Montana, to the Seaboard Oil Company of Delaware, Casper, Wyoming.

New officers of the New Orleans Geological Society, New Orleans, Louisiana, are: president, JOE B. HUDSON, Humble Oil and Refining Company; vice-president, FRED S. GOERNER, California Company; secretary-treasurer, AME VENNEMA, Schlumberger Well Surveying Corporation.

K. A. SIMMONS has resigned his position as chief geologist for the Kingwood Oil Company, Oklahoma City, Oklahoma, to become division manager for the Anderson-Prichard Oil Corporation at San Antonio, Texas.

T. N. ROBERTS, recently with the British-American Oil Company and HAROLD E. MCNEIL, formerly with the Great Lakes Carbon Corporation, have formed a partnership in consulting geology at Wichita, Kansas.

R. L. CLIFTON has retired as chief geologist and geophysicist for the Champlin Refining Company, Enid, Oklahoma, after many years with that company. He plans to continue his geological activity in independent work. His address is 1703 East Maple, Enid.

New officers of the Shreveport Geological Society, Shreveport, Louisiana, are: president, CLAUDE N. VALERIUS, Barnsdall Oil Company; vice-president, WALTER F. HAMILTON, Gulf Refining Company; secretary-treasurer, R. T. WADE, Schlumberger Well Surveying Corporation.

SAMUEL S. GOLDICH, of the Texas Bureau of Economic Geology and the United States Geological Survey, has accepted a position, beginning September 15, as associate professor of petrography and petrology in the department of geology at the University of Minnesota. He will fill the position vacated by the retirement of F. F. Grout.

H. BAGGELAAR has left The Hague, Netherlands, to be employed as paleontologist with the Anglo-Egyptian Oilfields, Ltd., Box 228, Shell House, 4 Sharia Cherifein, Cairo, Egypt.

DAVID M. WEBER is in the employ of the Gulf Research and Development Company, Pittsburgh, Pennsylvania.

Effective June 1, 1948, CLARENCE P. DUNBAR heads a new Division of Institutional Services at the University of Louisville, Louisville, Kentucky. This new division is composed of units formerly known as the Comptrollers Office, Cashiers Office, Purchasing Office, and Bureau of Institutional Research and will be housed together in the Navy Building on the Belknap Campus of the University of Louisville.

H. H. RENZ-IN DER GAND is division geologist with the Caribbean Petroleum Company, Apartado 809, Caracas, Venezuela. He was recently transferred from Maracaibo.

New officers of the North Texas Geological Society, Wichita Falls, Texas, are: president, J. J. RUSSELL, independent geologist, 907 Staley Building; vice-president, JOSEPH W. MCDONALD, Shell Oil Company, Inc.; secretary-treasurer, RALPH H. MCKINLEY, Panhandle Producing and Refining Company, Box 1191, Panhandle Building.

ROBERT F. WALTERS, formerly with the Gulf Oil Corporation, in Tulsa, Oklahoma, is associated with the Heathman-Honaker Drilling Company, Inc., at 603 Denham Building, Denver, Colorado.

HARRY B. HILL, retired from Government service after 30 years as petroleum engineer and consulting engineer, is at Green Tree, New Mexico. For many years he was in the office of the United States Bureau of Mines at Dallas, Texas.

EDWARD MCFARLAN, JR., has entered the employ of the Humble Oil and Refining Company as junior geologist at Corpus Christi, Texas.

DANIEL E. NISLEY is with the Hudson's Bay Oil and Gas Company, Ltd., at Calgary, Alberta, Canada.

STEVEN S. ORIEL is working on the geology of the Hot Springs area for the Department of Conservation and Development of North Carolina, as part requirement for the degree of Ph. D. at Yale University.

JAMES C. SCOTT, formerly with the Shell Oil Company, Inc., is with the Husky Oil and Refining Company, Calgary, Alberta, Canada.

RALPH H. WILPOLT has resigned from the American Smelting and Refining Company in New Mexico to return to the United States Geological Survey.

BURDETTE A. OGLE has left the employ of the Union Oil Company of California to return to the University of California to work for the Ph. D. degree. His address is 2745 Grove Street, Berkeley, California.

GORDON W. PRESCOTT, formerly with the Illinois Geological Survey, is with the Corps of Engineers, Garrison District, working on the Garrison Dam Project, Fort Lincoln, Bismarck, North Dakota.

MARTIN MATSON has left the Cities Service Company. He is employed by the Pan American Producing Company, Corpus Christi, Texas.

V. E. PETERSON has left the geological department of the Magnolia Petroleum Company, Roswell, New Mexico, to become geologist for the Equity Oil Company, Salt Lake City, Utah.

ROY HAYES GUESS is no longer with the Humble Oil and Refining Company, having joined the Newman Brothers Drilling Company, San Antonio, Texas.

CHARLES C. CLARK has resigned from the Carter Oil Company to accept the position of geologist with the Texas Eastern Transmission Corporation, Shreveport, Louisiana.

WILLIAM A. RIGGS has changed his connections from industrial geologist with the Atlantic Coast Line Railroad to industrial engineer with the Gulf, Mobile, and Ohio Railroad, at Mobile, Alabama.

FRANK RIEBER, head of the Rieber Research Laboratory, New York, died June 30, at the age of 58 years.

New Officers of the Corpus Christi Geological Society, Corpus Christi, Texas, are: president, H. D. MCCALLUM, Humble Oil and Refining Company; vice-president, NORMAN D. THOMAS, Pure Oil Company; secretary-treasurer, JAMES D. BURKE, Seaboard Oil Company of Delaware.

GLEN W. LEDINGHAM, assistant chief geologist for the Western Gulf Oil Company, has been appointed chief geologist, succeeding the late ROBERT W. CLARK, at Los Angeles, California.

HALBERT H. BYBEE has left the Carter Oil Company to enter the employ of the Continental Oil Company at Fort Worth, Texas.

GEORGE S. BUCHANAN, of the Sohio Petroleum Company at Houston, Texas, has been promoted to the vice-presidency in charge of land and exploration.

NORMAN WARE EWBANK, JR., is with the Cities Service Oil Company, Houston, Texas.

H. R. WOFFORD, JR., recently with the Standard Oil Company of Argentina, may be addressed at 231 West Garita, San Antonio, Texas.

RALPH ODEN DAVIS has resigned his position as assistant professor of geology at the Colorado A. and M. College to become junior geologist with The Texas Company at Houston, Texas.

THOMAS CLEMENTS, head of the department of geology of the University of Southern California, is conducting the University's summer field geology class in the Cuyama River Canyon area, 25 miles east of Santa Maria. This is west of the recent development in the Cuyama Valley, in an area that at present is not known to be commercially interesting. Twenty-nine senior geology and petroleum engineering students make up the field party.

THOMAS A. HENDRICKS has resigned from the United States Geological Survey and has taken the position of consulting geologist to the foreign exploration department of the Stanolind Oil and Gas Company, Wright Building, Tulsa, Oklahoma.

THEODORE A. LINK has resigned from his position as chief geologist for Imperial Oil Limited, with which company he has been associated for 29 years. He will engage in consulting practice, and will announce his business address in Toronto, Ontario, and Calgary, Alberta, as soon as he has become established. In the meantime, he may be reached at his home address, No. 7 Grenadier Heights, Toronto 3, Ontario, Canada.

The Geological Forum of the Pacific Section of the Association presented the following program at Los Angeles, California, July 19. "Geology of the Gulf Continental Shelf," by J. BEN CARSEY, Humble Oil and Refining Company; "Mechanics of Faulting in the Los Angeles Basin," by ROBIN WILLIS, consultant; "Oil Development in Long Beach Harbor," by GEORGE R. AUGUST, Long Beach Harbor Department.

PITTSBURGH REGIONAL MEETING, OCTOBER 4–9, 1948

HOTEL WILLIAM PENN—HEADQUARTERS

ANNOUNCEMENT

A mid-year regional meeting of the American Association of Petroleum Geologists will be held in Pittsburgh, Pennsylvania, October 4–9, 1948. Members of the Pittsburgh Geological Society, which is acting as host society, are endeavoring to provide an attractive technical session and field trip which will make this meeting worth while. The general theme of the meeting will be "Appalachian Geology." A cordial invitation is extended to all A.A.P.G. members.

THOSE PRELIMINARY ANNOUNCEMENT POSTAL CARDS

About the middle of June you received a card requesting information on your plans to attend the meeting. If you have not already done so, please mark that return card and drop it in the mail today.

HOTEL RESERVATIONS

A postal card is enclosed which should be mailed promptly to make your room reservations at the Hotel William Penn. Reservations should be made directly with the hotel and not with a committeeman.

COSTS

The registration fee is tentatively set at $5. This will assist in defraying the cost of putting on the meeting. The total cost of the entire field trip, including transportation, guide book, plus meals and hotels probably will not exceed $70. The prices of rooms at the Hotel William Penn are listed on the enclosed card.

GENERAL OUTLINE OF PROGRAM

Monday, October 4	—Registration and technical session on 17th floor of Hotel William Penn
Night	Banquet and paper on Philosophy of Research
Tuesday, October 5	—Technical session
Night	Nothing scheduled at present
Wednesday, October 6	—First day of field trip, Pittsburgh to Harrisburg, Pa.
Thursday, October 7	—Field trip, Harrisburg, Pa., to Rochester, N. Y.
Night	Buffet supper for the group
Friday, October 8	—Field trip, Rochester, N. Y., to Niagara Falls and Buffalo. End of field trip except for those electing secondary recovery conference
Night	Banquet at Bradford, Pa., and paper on Secondary Recovery
Saturday, October 9	—Field inspection of the Bradford area, return to Pittsburgh Saturday afternoon

TECHNICAL SESSIONS

(Tentative program. Papers may be added, deleted, or the order may be revised)

MONDAY, OCTOBER 4 (MORNING)

1. General orientation paper reviewing geology and production of the Appalachian area, by R. E. Sherrill
2. Petrology and paleogeology of the Greenbrier limestone, by Gordon Rittenhouse
3. The Hemlock Grove Berea Sand pool, Meigs County, Ohio, by R. L. Alkire
4. The Fifth Sand pool (formerly known as McDonald and Robinson), Allegheny and Washington counties, Pa., by A. I. Ingham

(AFTERNOON)

A series of papers on the geology and occurrence of natural gas in the Oriskany sand of the Appalachian area.

5. Part A. The occurrence in faulted anticlines with particular reference to the Ellisburg, Harrison, and Woodhull trend, by F. H. Finn
6. Part B. The occurrence in low relief domes with particular reference to pools in South Beaver Township, Beaver County, Pa., and in Knox Township, Columbiana County, Ohio, by John T. Galey
7. Part C. Stratigraphic accumulation in the Cambridge area, Gurnsey and Tuscarawas counties, Ohio, by J. R. Lockett
8. Part D. Stratigraphic accumulation in the Jackson-Kanawha counties area of West Virginia, by A. H. McClain

(EVENING). Banquet

9. The philosophy of research, by E. R. Weidlein

TUESDAY, OCTOBER 5 (MORNING)

10. Geology and occurrence of natural gas in the Newburg horizon, Mayfield Township, Cuyahoga County, Ohio, by H. R. Rothrock
11. Some phases of oil and gas geology of the Ontario Peninsula, by W. A. Roliff
12. Geology and occurrence of oil in the Medina sand of the Blue Rock-Salt Creek, Ohio, pool, by James F. Swain
13. Geology and occurrence of oil in the Rose Hill area of Lee County, Virginia, by Byron Cooper
14. Results of studies of Silurian rocks east of the Allegheny Front in Pennsylvania, by Frank Swartz

(AFTERNOON)

15. Results of studies of Ordovician rocks east of the Allegheny Front in Pennsylvania, by C. E. Prouty

(Papers 14 and 15 will include a reference to reservoir rocks that are contained in these members)

16. Facies change in the Appalachian basin from west to east, by R. E. Bayles
17. Relationship of magnetic anomalies to surface structure east of the Allegheny Front in Pennsylvania, by H. R. Joesting and J. R. Balsley
18. Evolution of thought on Appalachian structure from Rogers to the present, by John Rodgers
19. Structure of the Basement complex of the Appalachian area, with particular reference to Pennsylvania, by Ernst Cloos

(EVENING)

20. Nothing scheduled at present

FRIDAY, OCTOBER 8 (EVENING). Dinner Meeting at Bradford, Pa.

21. The geological factors involved in secondary recovery, by Maynard M. Stephens

FIELD TRIP

SUMMARY OF ITINERARY

WEDNESDAY, OCTOBER 6

Pittsburgh to Harrisburg, about 215 miles. Pittsburgh to Turnpike entrance on Route 30. Turnpike to Somerset. Somerset to Stoystown on Route 53. Stoystown to Bedford on Route 30. We plan to leave the Turnpike at Somerset in order to stop at Grand View Point on the Allegheny Front. This is an excellent vantage point from which to view the physiography and geology of the western part of the Ridge and Valley Province, and will probably be a major stop of the day. Bedford to Middlesex on Turnpike. Middlesex to Harrisburg on Route 11. A. B. Cleaves' work along the Turnpike will be used.

Overnight stop in Harrisburg. Accommodations have been reserved at the Penn, Harris, and the Harrisburger hotels.

No banquet or group dinner is being planned in Harrisburg.

THURSDAY, OCTOBER 7

Group breakfast in Harrisburg.

Harrisburg to Rochester, New York, about 260 miles. Harrisburg to Sunbury on Route 14. Sunbury to Cohocton, N. Y., on U. S. Route 15. Cohocton to Canandaigua on Routes 371, 245, and 21. Canandaigua to Rochester on Routes 332 and 96. Bradford Willard has logged the Pennsylvania part of this trip. John G. Broughton and staff from the New York State Science Service are working on the New York part of the trip. Overnight stop in Rochester at the Sheraton Hotel. A buffet supper has been offered for the group by the Bausch and Lomb Optical Company. Arrangements are being made to have the Rochester Museum open for the delegates. Interesting geological displays are exhibited there. It is possible that some of Rochester's industries will have exhibits also.

FRIDAY, OCTOBER 8

Group breakfast in Rochester at the Sheraton Hotel
Geology of Rochester Gorge
Rochester to Niagara Falls on Route 104, about 85 miles
Geology of Niagara Gorge
Devonian-Silurian unconformity in limestone quarry near Buffalo. For those who do not go to Bradford, this will be the end of the trip.

In order to provide the necessary facilities at this point, the following information must be acquired at registration time

1. Those going to Bradford
2. Those requiring transportation from Buffalo directly to Pittsburgh on Friday afternoon

There will probably be no stops between Rochester and Niagara Falls, but the route will be logged. From Niagara Falls to Bradford, the log follows Route 16, and there may be a short stop at Rock City if time permits. It is about 115 miles from the Falls to Bradford on this route.

The caravan should be in Bradford in time for the evening banquet.

SATURDAY, OCTOBER 9

Inspection of oil fields in the Bradford area. Return to Pittsburgh.

PITTSBURGH GEOLOGICAL SOCIETY
OFFICERS, 1948–1949

President: John T. Galey
Vice-president: W. B. Robinson
Treasurer: S. S. Galpin
Secretary: J. C. Patton

COMMITTEE CHAIRMEN

General: H. R. Brankstone
General arrangements: Shailer S. Philbrick
Program: John T. Galey
Field-trip: George C. Grow
Finance: S. S. Galpin
Publicity: W. B. Robinson

NEW ROCK-COLOR CHART NOW AVAILABLE

The new Rock-Color Chart is now available and can be purchased from the Division of Geology and Geography, National Research Council, Washington 25, D. C. for $5.50 per copy. This chart is designed especially for field use but is suitable also for use in the office or laboratory. It consists of 8 sheets, 5 by 7½ inches, and will fit conveniently in the

back of a field notebook. It includes 115 colors which indicate the range of rock colors for all purposes, and a brief text explains the system used for the chart arrangement and the color names.

The color names have been chosen to agree with the ISCC-NBS system[1] which is already accepted by a large number of scientific organizations. The choice was designed to select a system of simple rock-color names (such as *dark reddish brown*) sufficiently standardized to be acceptable to color scientists and sufficiently useful to be satisfactory to both field and laboratory geologists.

The form and arrangement of the chart are based on the Munsell system, the most widely accepted system of color identification in the United States. In addition to the color names, the Munsell numerical designation is placed under each color for the use of those geologists who wish to make fine color distinctions by interpolation between the colors shown on the chart.

The base chart was printed by the Government Printing Office and the color chips have been hand-colored and stuck onto the charts by the Munsell Color Company of Baltimore, Maryland. The colors are as permanent as it is possible to make them, and such color chips in the red, yellow, and brown ranges have been used successfully on the Soil Color Names Charts of the Department of Agriculture for nearly 10 years.

The Rock-Color Chart was prepared by the Rock-Color Chart Committee representing the following organizations.

E. N. Goddard, chairman, United States Geological Survey
Parker D. Trask, Geological Society of America
Ronald K. DeFord, American Association of Petroleum Geologists
Olaf N. Rove, Society of Economic Geologists
Joseph T. Singewald, Jr., and R. M. Overbeck, Association of American State Geologists

This committee is now a sub-committee of the Committee on Symposium on Sedimentation, Division of Geology and Geography of the National Research Council.

RONALD K. DEFORD

The Indiana-Kentucky Geological Society, Evansville, Indiana, has elected the following officers: president, E. J. COMBS, Sun Oil Company; vice-president, MAYNARD ROGERS, independent, 417 Court Building; secretary-treasurer, D. G. SUTTON, Sun Oil Company. Additional executive officers are GEORGE E. TAYLOR, Continental Oil Company, and NIELS GEORGESEN, independent, and J. ALBERT BROWN, Sohio Petroleum Company.

RUFUS M. SMITH has resigned from the Panhandle Eastern Pipe Line Company at Kansas City, Missouri, after being with the company since 1936, to accept a position with the Continental Oil Company in Los Angeles, California.

WILLIAM B. LEAVITT, geologist with the Amerada Petroleum Corporation, Tulsa, Oklahoma, died at Barnes Hospital, St. Louis, Missouri, June 24, at the age of 35 years.

MILTON R. SCHOLL, JR., has changed his connection from the Moore Exploration Company to the Sun Oil Company at Midland, Texas.

ALEC N. OSANIK has changed his address from the School of Geology, Louisiana State University, to the Waterways Experiment Station, Vicksburg, Mississippi.

THOMAS R. POLK, of the University of Oklahoma, is in the employ of the Carter Oil Company, Tulsa.

[1] National Bureau of Standards Research Paper RP 1239, now under revision.

DONALD A. MYERS, of Stanford University, is with the United States Geological Survey, Fuels Section.

KENNEDY R. MARBLE, of Denver, Colorado, is with the Imperial Oil Limited at Calgary, Alberta, Canada.

C. J. Peterson died, May 8, at the age of 61 years at Amarillo, Texas. He was chief geologist for the Texoma Natural Gas Company many years.

ERNST A. RITTER, of N. V. de Bataafsche Petr. Mij., The Hague, Holland, is retiring to Switzerland where his home address is Im Sesselacker 18, Basel.

President PAUL WEAVER addressed the Eastern Section of the Association, New York City, July 22. His subject was "A Complete Marine Evaporite Cycle," illustrated by slides. His talk followed a brief business session and dinner at the Mining Club.

BROOKS PIERCE has resigned as division geologist for the Shell Oil Company, Inc., to enter consulting work. His office address is 1411 Union National Bank Building, Wichita, Kansas.

W. W. HAMMOND has resigned from the Magnolia Petroleum Company to work with Fair-Woodward, 1704 Alamo National Building, San Antonio, Texas.

MILTON H. KUHLEMAN has completed work toward the master's degree and is now employed by The California Company as geologist in the stratigraphic section at New Orleans, Louisiana.

KEITH E. ANDERSON resigned from his position as ground-water engineer with the Missouri Geological Survey, June 5, to become geologist with the Iowa Geological Survey at Iowa City.

JOHN A. MACKINTOSH is with the Wil-Tex Oil Corporation, Corpus Christi, Texas.

The address of Colonel O. F. KOTICK, USA, GSC, is Deputy Director, Naval Petroleum Reserves, Room 1046, T-3 Building, Navy Department, Washington 25, D. C.

JOHN C. MCCAMPBELL has left the department of geology at Rutgers University to accept a position as associate professor in geology at Tulane University, New Orleans, Louisiana.

KURT H. DE COUSSER, of the Socony Vacuum Oil Company, White Star Division, Lansing, Michigan, has been elected chairman of the Michigan Oil Advisory Board which handles matters of proration and spacing patterns.

The new officers of the Panhandle Geological Society, Amarillo, Texas, are: president, ROBERT J. GUTRU, Cities Service Oil Company; vice-president, L. B. FUGITT, Stanolind Oil and Gas Company; secretary-treasurer, FRED S. ALEXANDER, Standard Oil Company of Texas.

G. D. HANNA, a pioneer in the application of micropaleontology to oil prospecting in California, retired as paleontologist for the Tide Water Associated Oil Company, June 1, on the completion of his twenty-fifth year. During these years he has also held the position of curator of paleontology and geology at the California Academy of Sciences. His recently enlarged duties at the Academy as assistant administrator together with special work on the building of the new Planetarium hastened his decision to retire from the oil company. C. C. CHURCH, his associate for many years in the oil-company laboratory will succeed him. CHARLES STURZ, a graduate of Stanford, will be associated with Church.

WALTER P. KETTERER is leaving Canada where he has been in the employ of the Dominion Gulf Company to resume work in the Ardmore, Oklahoma, office of the Gulf Oil Corporation.

JEMES H. DE LONG, JR., has left the Phillips Petroleum Company to join the Superior Oil Company, 1014 Citizens National Bank Building, Evansville, Indiana.

BERNHARD KUMMEL, geologist with the Bureau of Economic Geology, University of Texas, has been appointed assistant professor of geology at the University of Illinois.

RICHARD CARL BANISTER has moved from Tulsa, Oklahoma. His address is the Standard Oil Company of Texas, Box 1660, Midland, Texas.

JAMES S. YOLTON has returned from work with the Creole Petroleum Corporation, Temblador district, Caripito, Venezuela. He may be addressed at 812 Forty-Sixth Street, Rock Island, Illinois.

WILLIAM MCBEE, JR., graduated in June from the University of Kansas with the degree of master of science in geology and is an exploration geologist with The California Company at New Orleans, Louisiana.

FRANK E. BYRNE is with the United States Geological Survey and the Kansas State College at Manhattan, Kansas.

ROY O. JACKSON, recently with the Magnolia Petroleum Company at Lake Charles, Louisiana, is teaching in the department of geology, Oklahoma A. and M. College, Stillwater, Oklahoma.

N. W. NICHOLS, formerly of the Superior Oil Company, may be addressed in care of the Rio Bravo Oil Company, Limited, 203 Wilson Electric Building, Calgary, Alberta, Canada.

JACK W. NORDQUIST recently resigned his position as assistant geologist with the United States Geological Survey to accept a position of geologist with the Wasatch Oil Company, a Phillips Petroleum Company subsidiary. His address is 512 Seventh Street, North, Great Falls, Montana.

GERALD A. WARING retired from the United States Geological Survey on May 31, after 42 years of professional work, half of which was spent in the Government service. He and Mrs. Waring expect to reside in California. Their address is 641 Wellesley Street, Palo Alto, California.

ARDMORE GEOLOGICAL SOCIETY FIELD TRIP, JUNE 18–19, 1948

The Ardmore Geological Society sponsored a field trip in southern Oklahoma, June 18–19. The conference opened on the night of June 17, when JOHN L. FERGUSON of Tulsa presented the colored movies of last year's trip of the Tulsa Geological Society to the Ouachita Mountains. On June 18 the trip was led by C. W. TOMLINSON and covered the Pennsylvanian sediments in the area north of Ardmore. A banquet was held that night at the Ardmore Y. W. C. A. and a paper entitled "Correlation of the Pennsylvanian Formations of Oklahoma and Texas" was presented by MONROE G. CHENEY of Coleman, Texas. On June 19 the trip was led by JEROME WESTHEIMER and covered the Pennsylvanian sediments in the area south of Ardmore. Approximately 250 people attended the field trip and banquet.

The guidebook available for the trip includes two aerial photographs of the Ardmore Basin area. A limited number of copies are available at $4.50 per copy. Anyone interested in acquiring the guidebook may contact FRANK MILLARD of the Schlumberger Well Surveying Corporation, Ardmore, Oklahoma.

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Source Data

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By

J. V. HOWELL AND A. I. LEVORSEN
Tulsa, Oklahoma, and Stanford University, California

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- C. Dictionaries, glossaries, encyclopedias, statistics, handbooks
- D. Miscellaneous books and publications of general geological interest
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- G. State and Province geological maps
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THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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Stanolind Oil and Gas Company

Regular Meetings: 7:30 P.M., Geological Room, University of Wichita, first Tuesday of each month. Noon luncheons, first and third Monday of each month at Wolf's Cafeteria. The Society sponsors the Kansas Well Log Bureau, 412 Union National Bank Building, and the Kansas Well Sample Bureau, 137 North Topeka. Visiting geologists and friends welcome.

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Vice-President and Program Chairman - - -
- - - - - - - - - - - - Fred S. Goerner
California Company, 1818 Canal Building
Secretary-Treasurer - - - - - Ame Vennema
Schlumberger Well Surveying Corporation

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Schlumberger Well Surveying Corporation
Box 92

Meets monthly, September to May, inclusive, in the State Exhibit Building, Fair Grounds. All meetings by announcement.

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Treasurer - - - - - - - - Philip R. Allin
Gulf Oil Corporation

Meetings: Dinner and business meetings third Tuesday of each month at 7:00 P.M. at the Majestic Hotel. Special meetings by announcement. Visiting geologists are welcome.

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Meetings: First and third Thursdays of each month, from October to May, inclusive, at 7:30 P.M., The Creole Room, LeFleur's Restaurant, Jackson, Mississippi. Visiting geologists welcome to all meetings.

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Schlumberger Well Surveying Corp., Box 747

Dinner meetings will be held at 7:00 P.M. on the first Wednesday of every month from October to May, inclusive, at the Ardmore Hotel.

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Meetings: Technical program each month, subject to call by Program Committee, Oklahoma City University, 24th Street and Blackwelder. Luncheons: Every second and fourth Thursday of each month, at 12:00 noon, Y.W.C.A.

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U. S. Geological Survey
Federal Building

Meetings: First and third Mondays, each month, from October to May, inclusive, at 8:00 P.M., University of Tulsa, Student Union or Tyrrell Hall. Luncheons: Every Friday (October-May), Chamber of Commerce Building.

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Meetings held each month, except during the summer. All meetings and other activities by special announcement.

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Box 1939

Meetings: 2d Thursday of each month, 7:30 P.M., Wooten Hotel.

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Regular luncheons, every Thursday, Terrace Annex Room, Robert Driscoll Hotel, 12:00. Special night meetings by announcement.

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Meetings: Monthly luncheons and night meetings by announcement.

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Stanolind Oil and Gas Company
Box 660

Luncheons: Each week, Monday noon, Blackstone Hotel.
Evening meetings and programs will be announced. Visiting geologists and friends are welcome.

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Stanolind Oil and Gas Company
Box 1410
Secretary-Treasurer - - - Millicent A. Renfro
Texas Pacific Coal and Oil Company, Box 2100

Meetings: Luncheon at noon, Hotel Texas, first and third Mondays of each month. Visiting geologists and friends are invited and welcome at all meetings.

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Schlumberger Well Surveying Corporation
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Regular meeting held the second and fourth Mondays at noon (12 o'clock), Mezzanine floor, Rice Hotel. For any particulars pertaining to the meetings write or call the secretary.

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Vice-President - - - - Joseph W. McDonald
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Secretary-Treasurer - - - Ralph H. McKinley
Panhandle Producing and Refining Company, Box 1191

Meetings: Luncheon 1st and 3d Wednesdays of each month, 12:00 noon, Y.W.C.A. Evening meetings by special announcement. Visiting geologists and friends are cordially invited to all meetings.

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Shell Oil Company
2000 Alamo National Building

Secretary-Treasurer - - - - Maurice E. Forney
Atlantic Refining Company
1728 Milam Building

Meetings: One regular meeting each month in San Antonio. Luncheon every Monday noon at Milam Cafeteria, San Antonio.

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Secretary - - - - - - - - Clyde W. Turner
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Treasurer - - - - - - - - - Jane M. Johnson
Permian Basin Sample Laboratory, Box 1653

Meetings will be announced.

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268 Oakwood Road, Charleston, W.Va.

Editor - - - - - - - - - W. T. Ziebold
Thomas Circle Road, Charleston, W.Va.

Meetings: Second Monday, each month, except June, July and August, at 6:30 P.M., Daniel Boone Hotel.

WYOMING

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POSSIBLE FUTURE OIL PROVINCES OF THE UNITED STATES AND CANADA

A symposium conducted by the Research Committee of The American Association of Petroleum Geologists, A. I. Levorsen, chairman. Papers read at the Twenty-sixth Annual Meeting of the Association, at Houston, Texas, April 1, 1941, and reprinted from the Association *Bulletin*, August, 1941.

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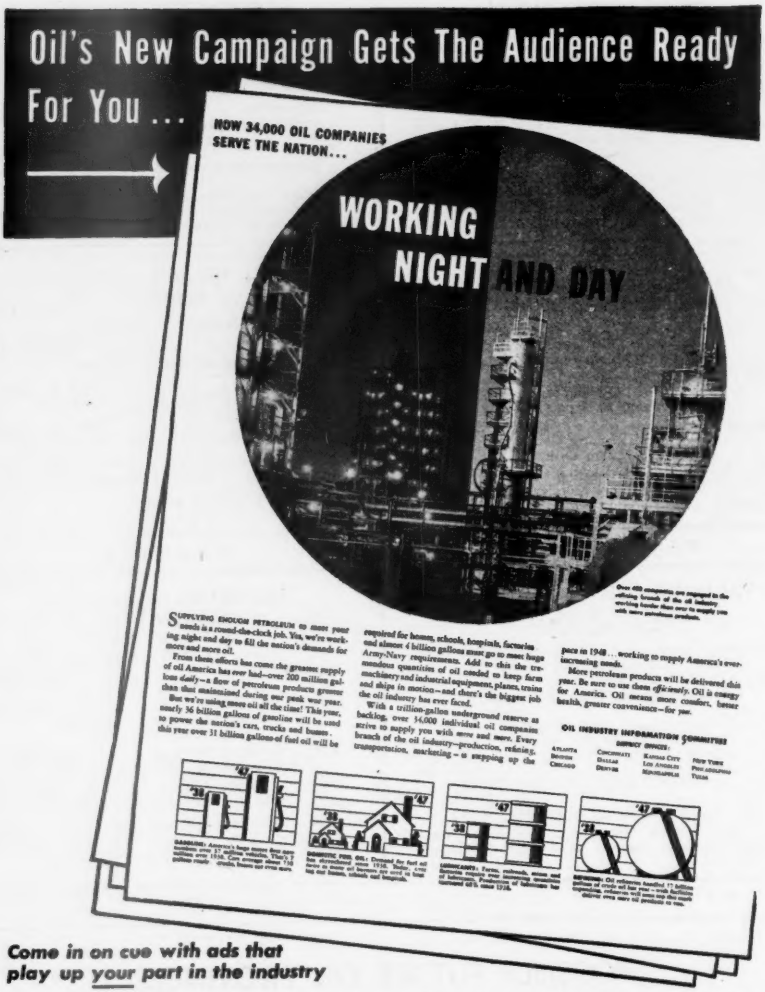
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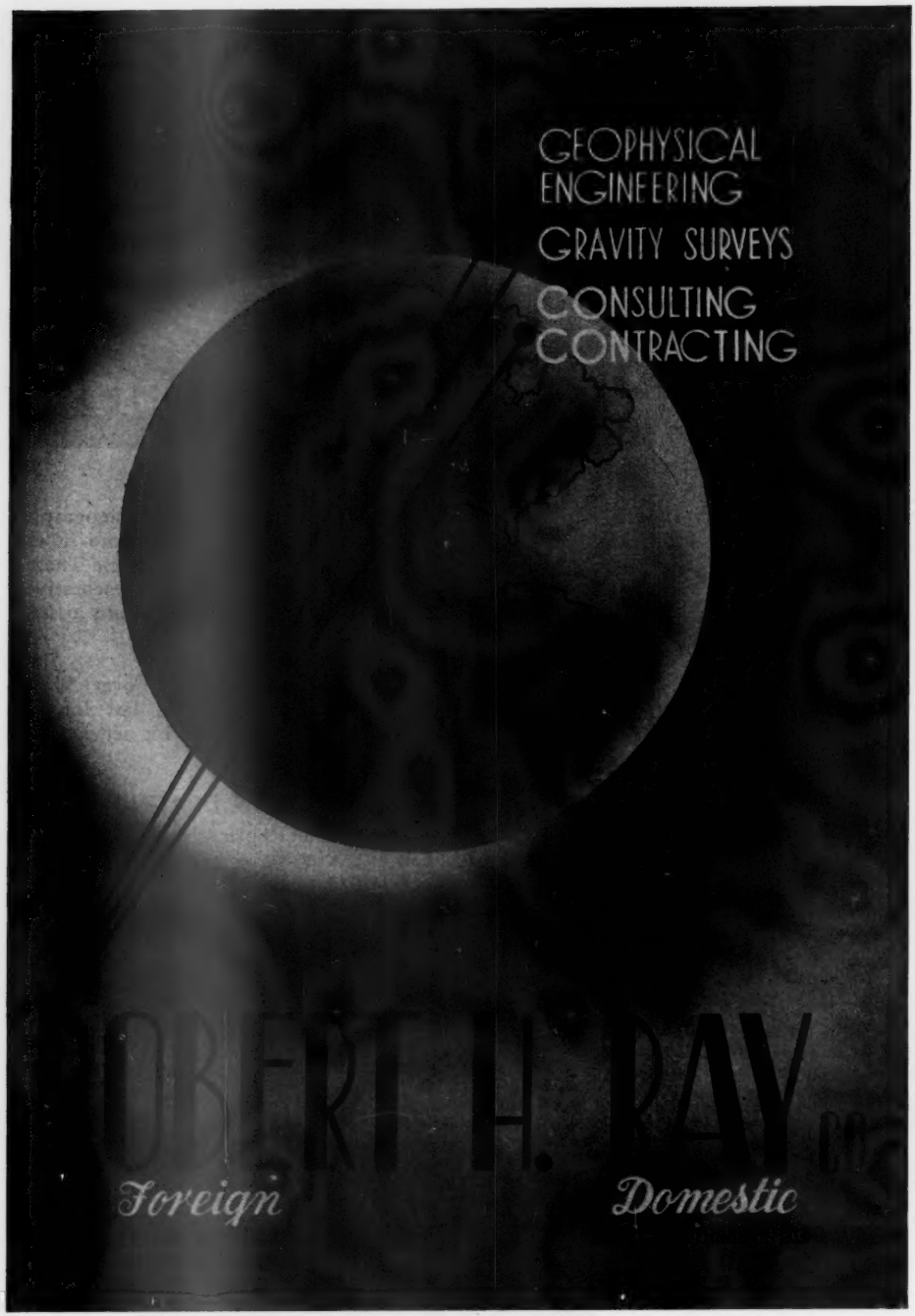
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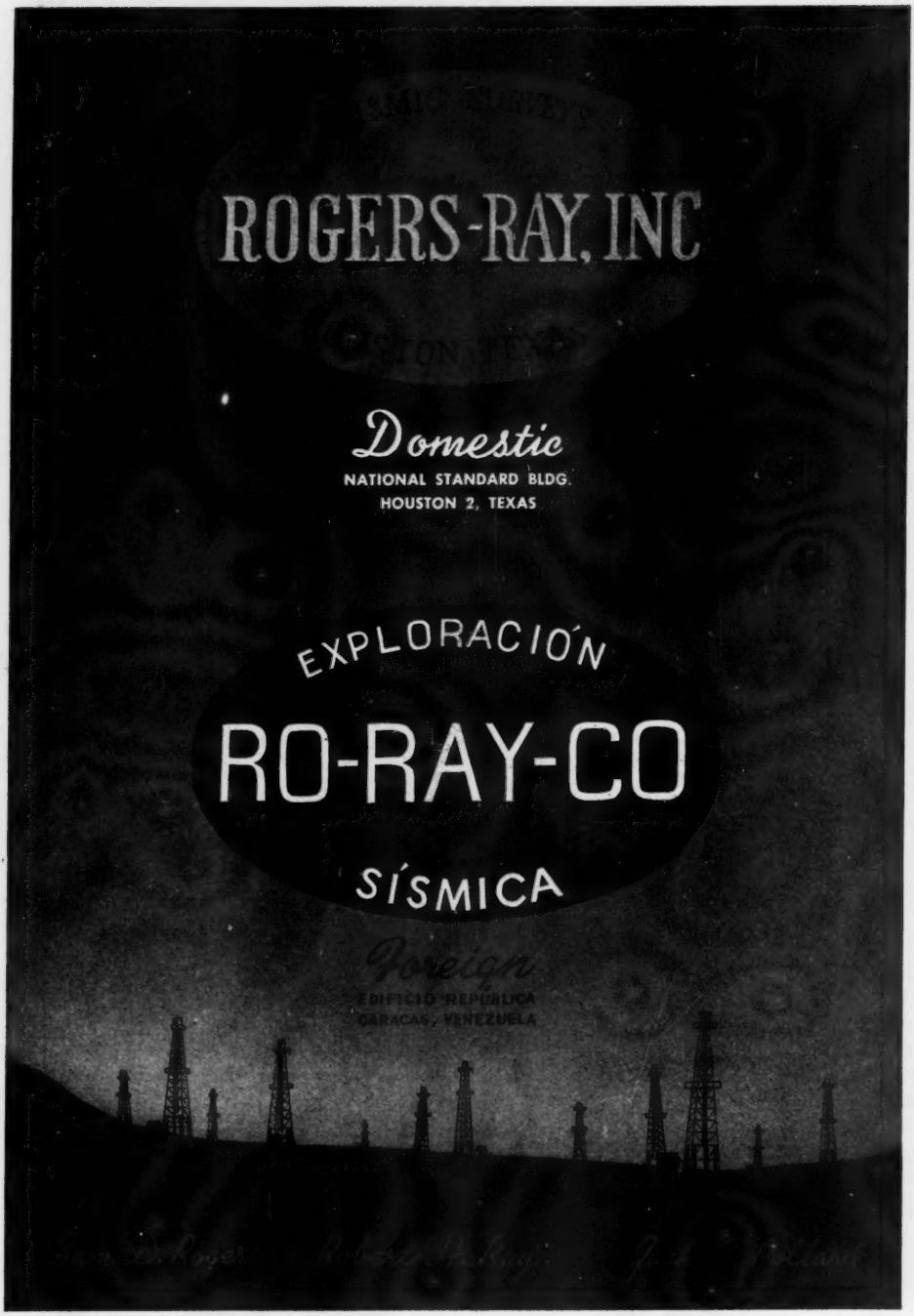
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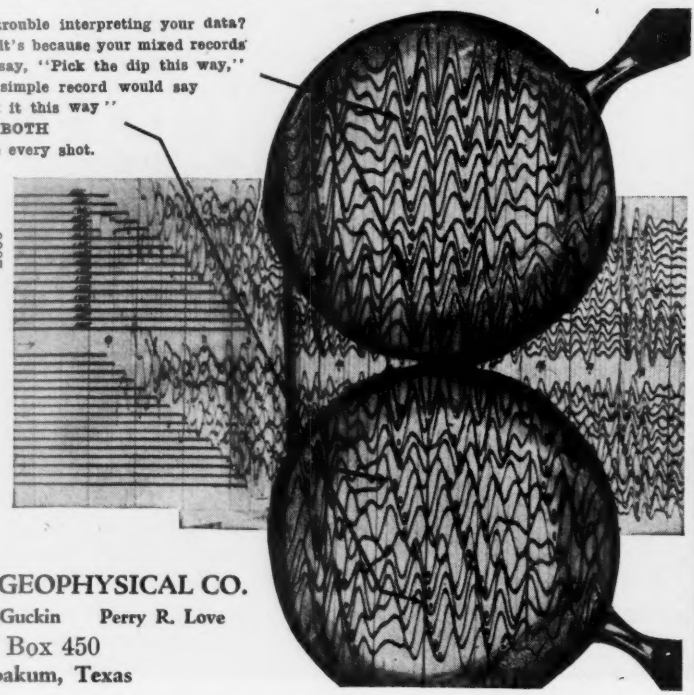

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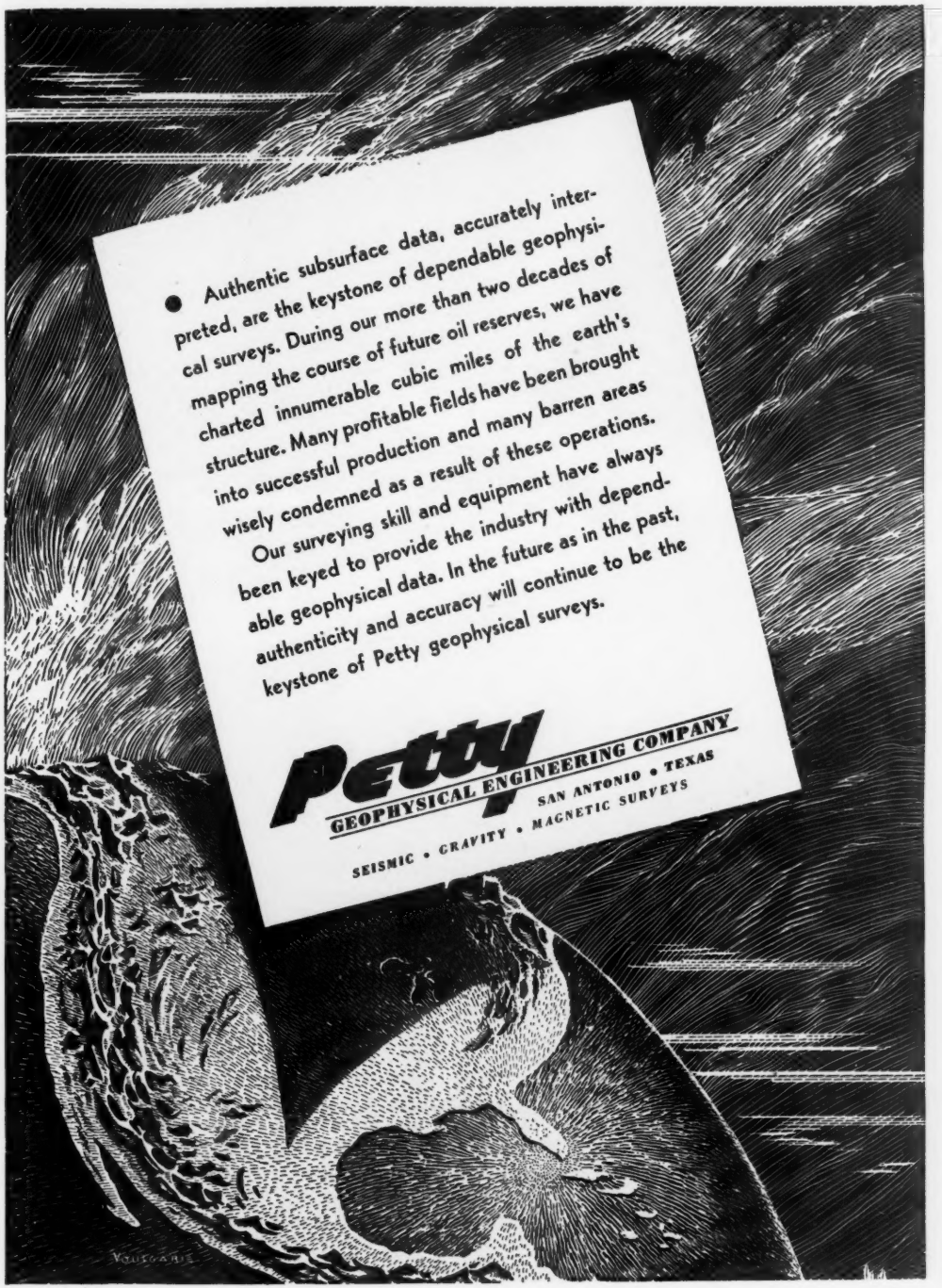
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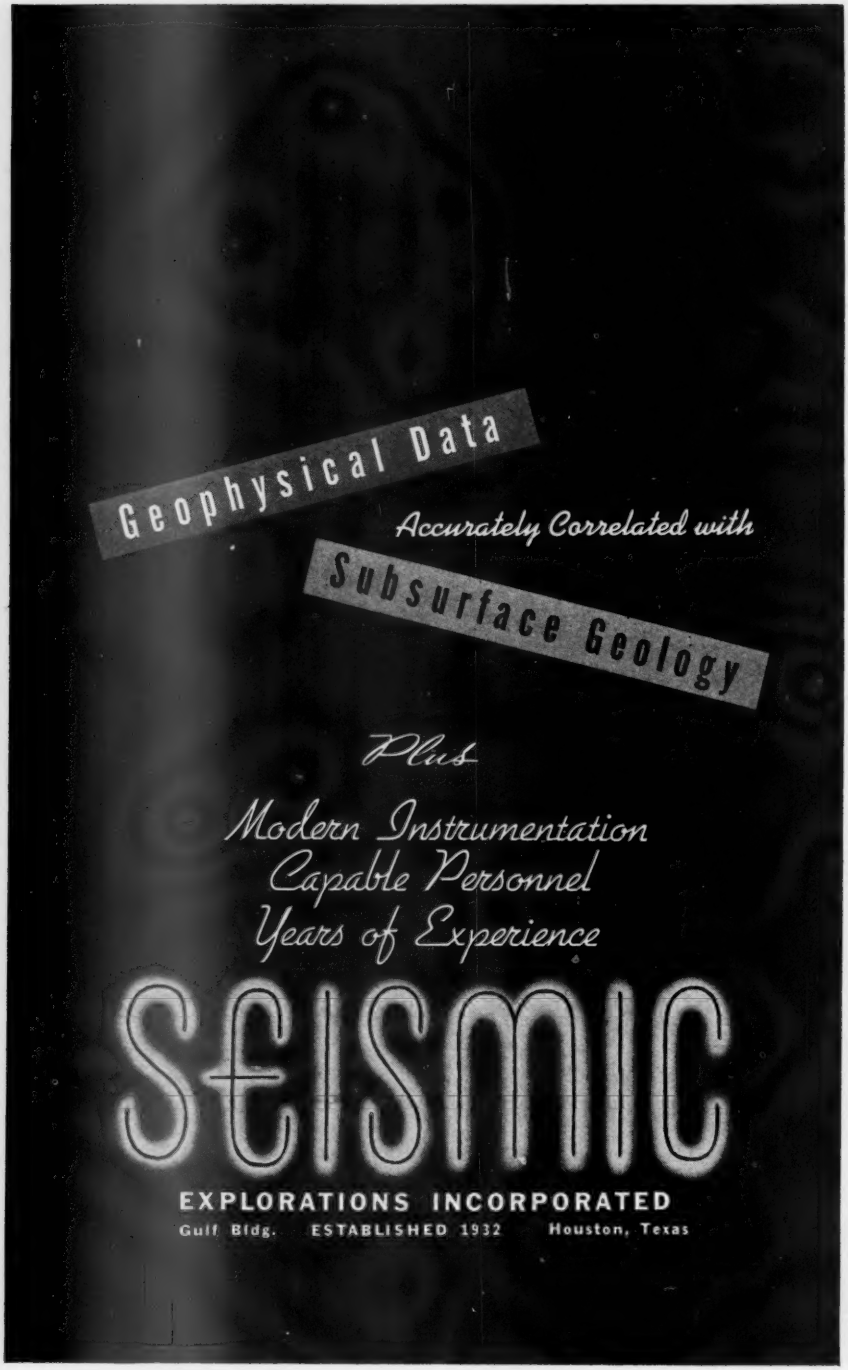
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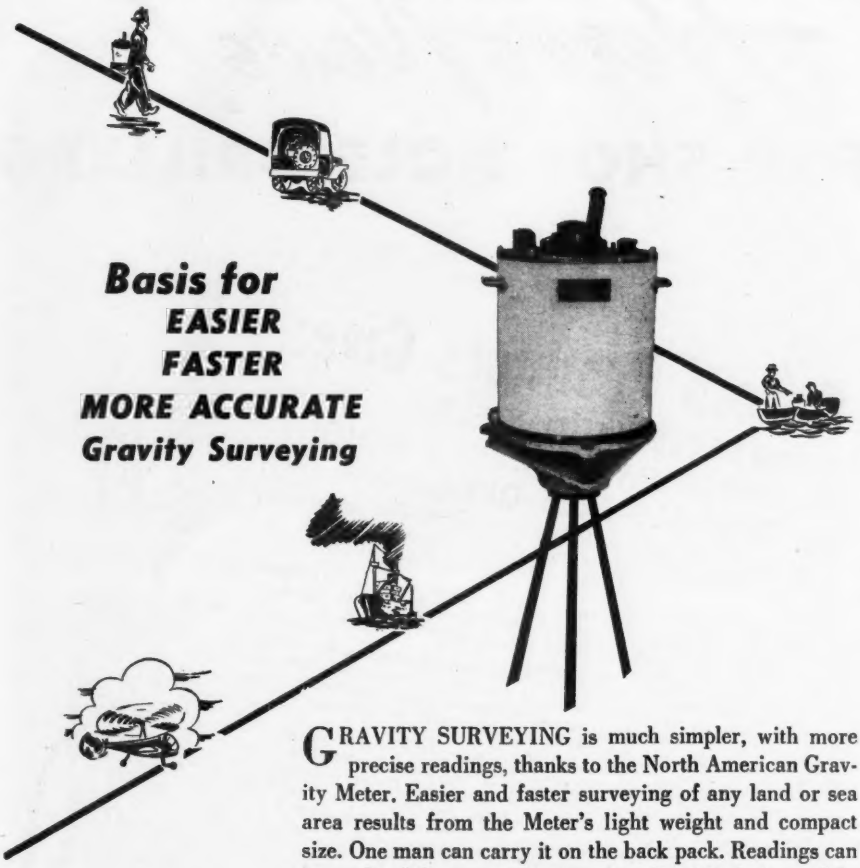

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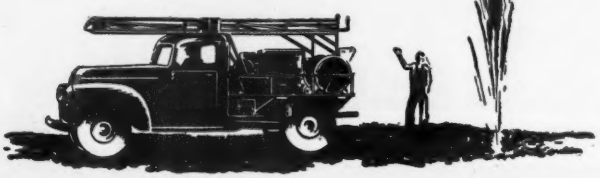

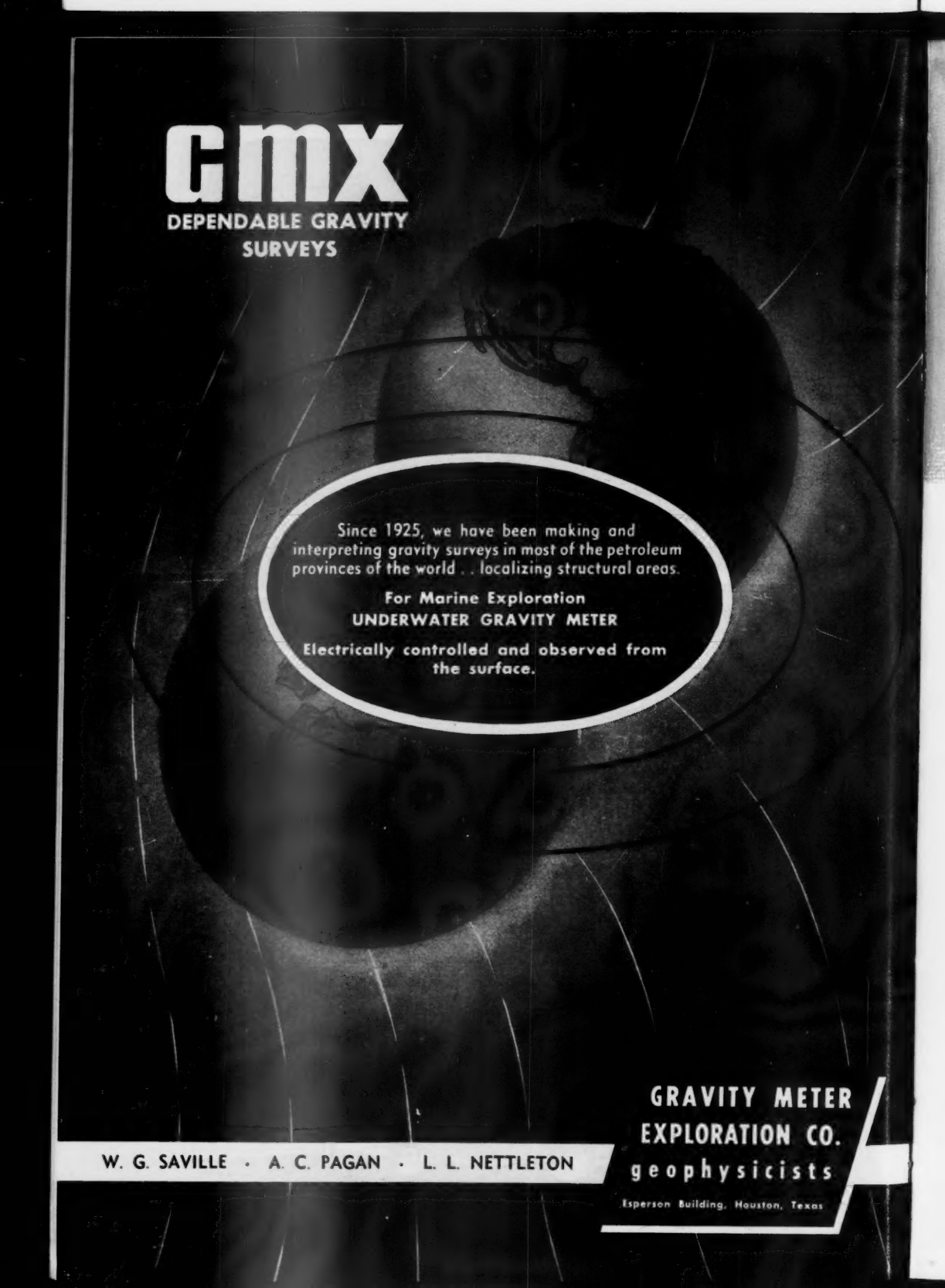
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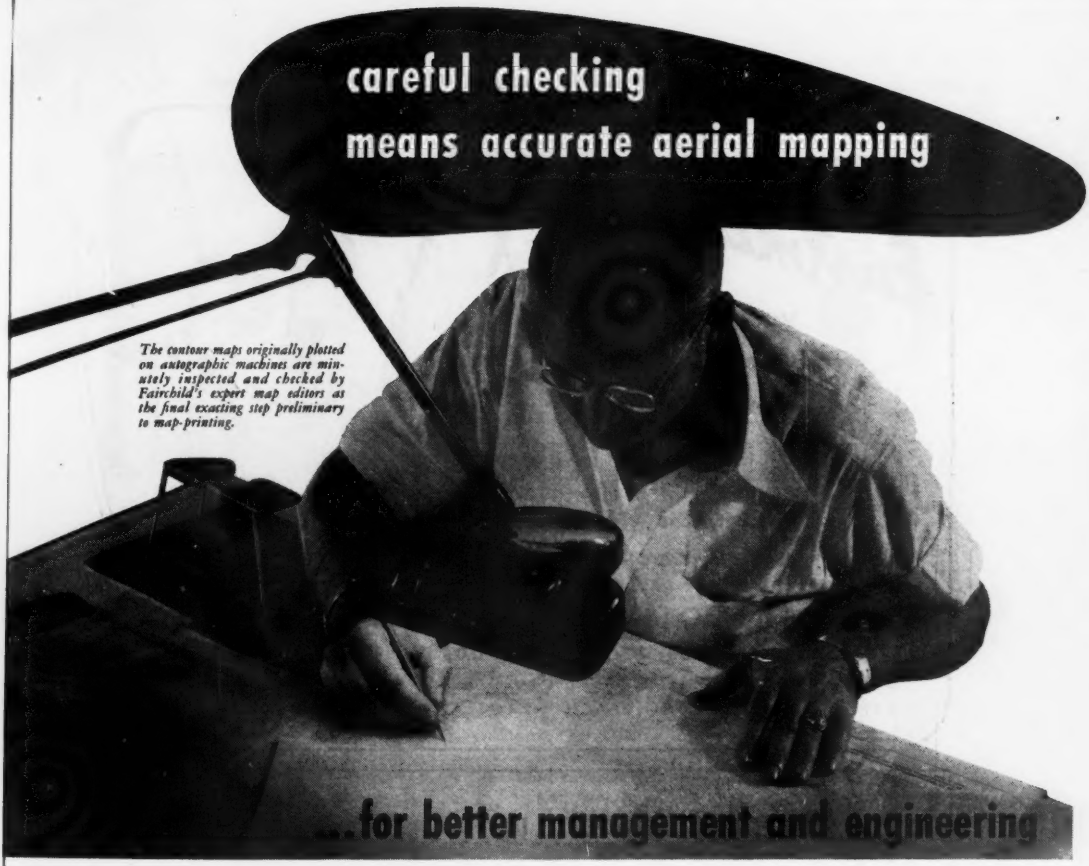

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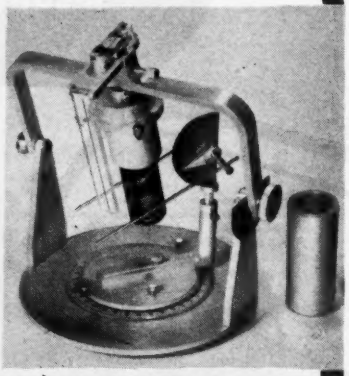

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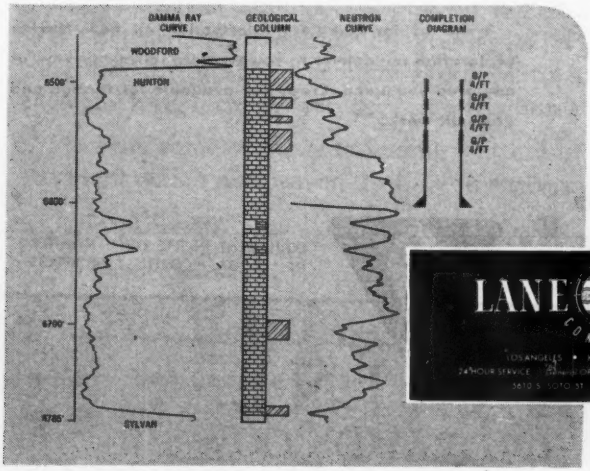

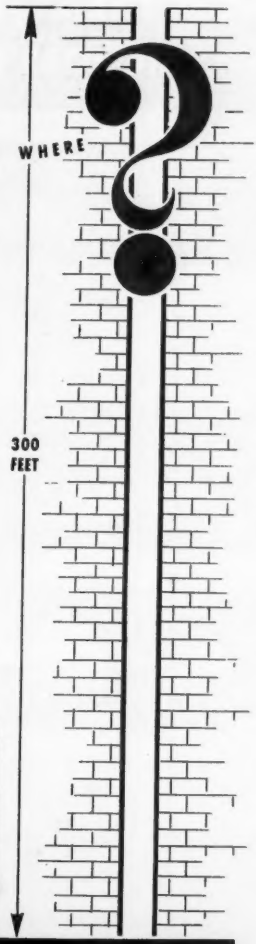

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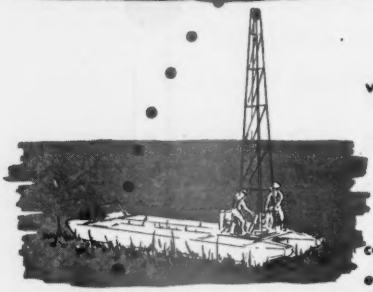

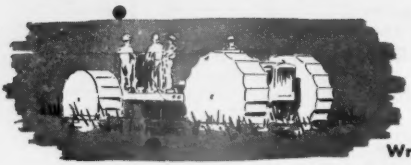

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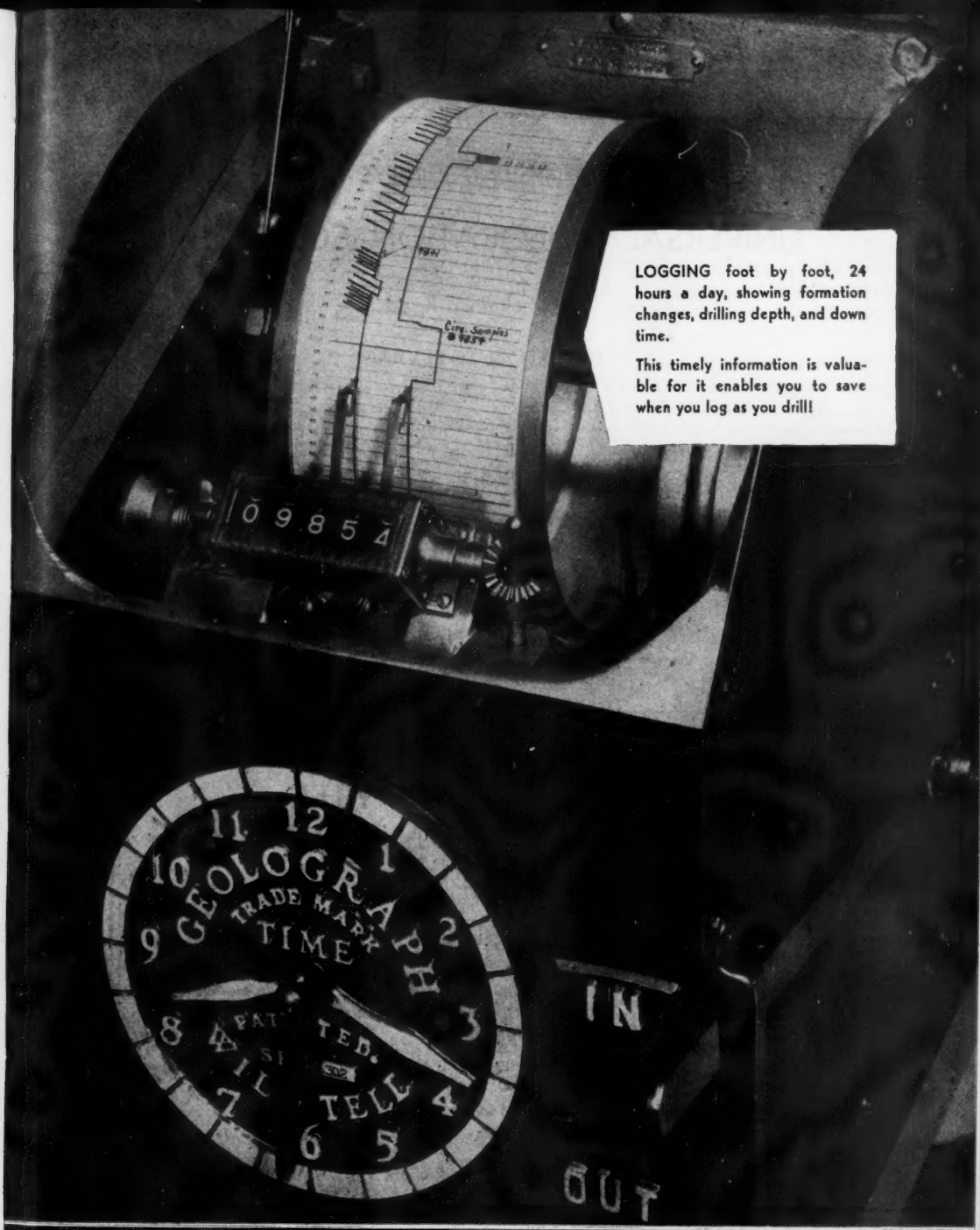

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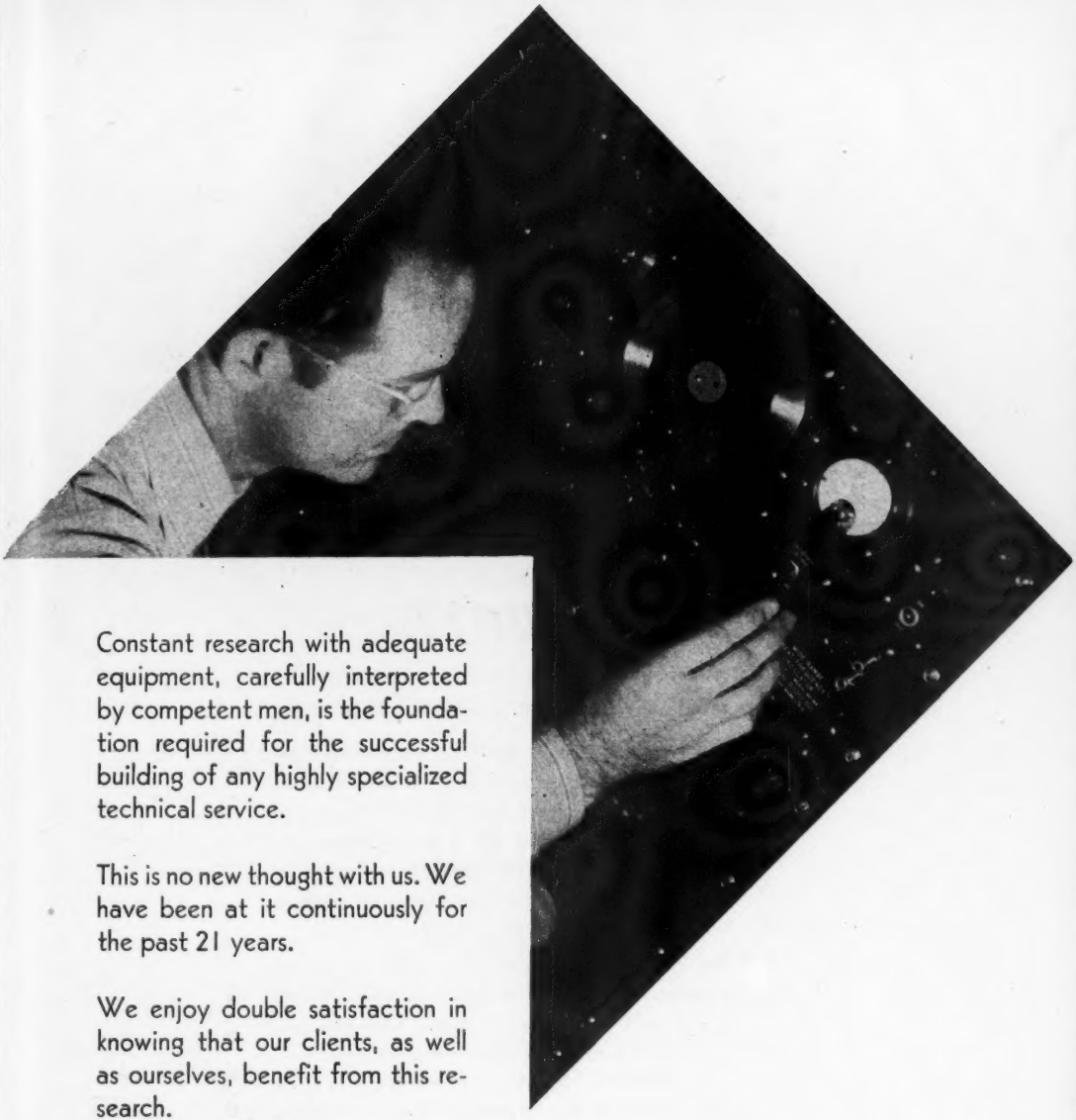

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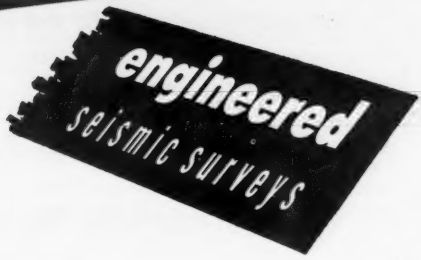

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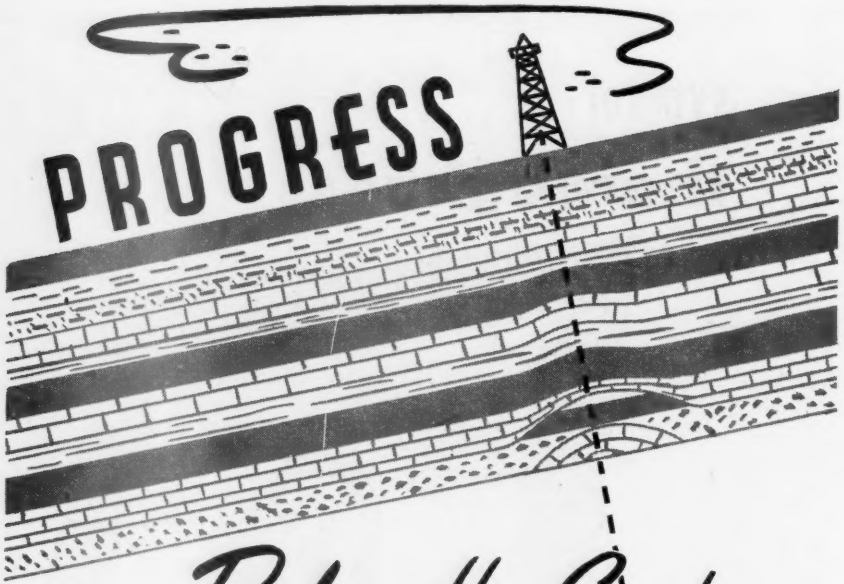

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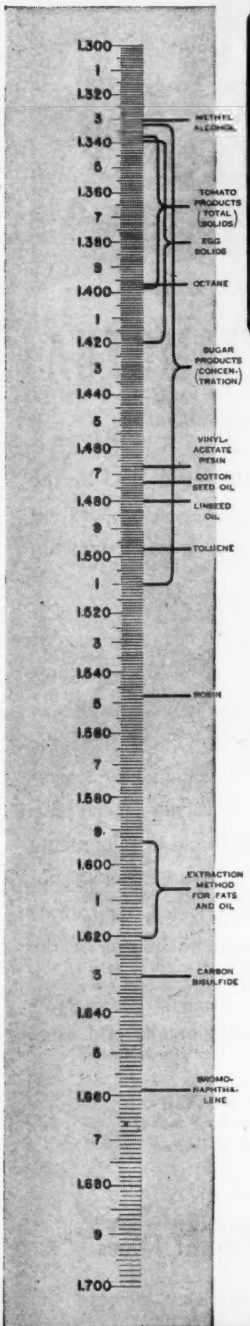

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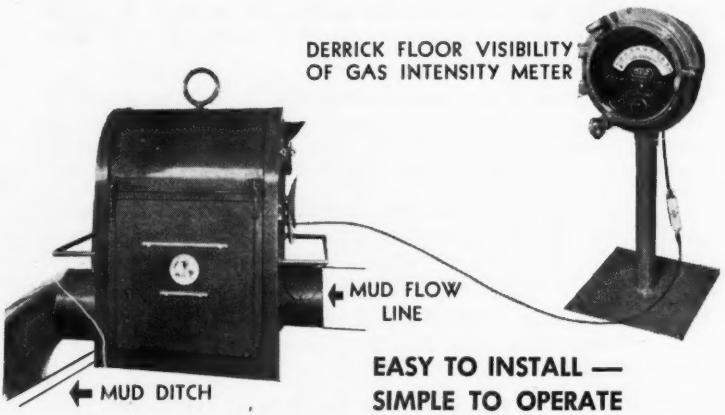

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NO. 9—172 pp. BRIT. COLUM.: Mississippian. CALIF.: Salt Creek. GEN.: Faults. KAN.: Up. Ordovician LA.: Tidal basins. N. MEX.: Triassic, Pecos Valley. ROCKY MTNS.: Jurassic. TEX.: Tidal basins. WYO.: Paleozoic and Mesozoic.

NO. 10—204 pp. ALA.: Black Warrior Basin. COLO.: Freezeout Creek fault, Baca Co. FLA.: Oil. GEN.: Microbial transformation; geomorphology; Cretaceous, SE. U.S.; onlap and strike-overlap; dip computation; perspective diagrams. GULF COAST: Cenozoic. MISS.: Black Warrior Basin. OKINAWA: Geology.

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NO. 7—184 pp. CAL.: Fractured rock reservoirs. GEN.: Presidential addresses; petroleum in E.R.P.; isopachous maps of sands; geology, 1907–47; survey of students. GULF: Artesian salt. N. D.: Sentinel Butte sh.: OKLA.: Up. Cambrian. W. INDIES: Tertiary Cipero marl; Curacao.

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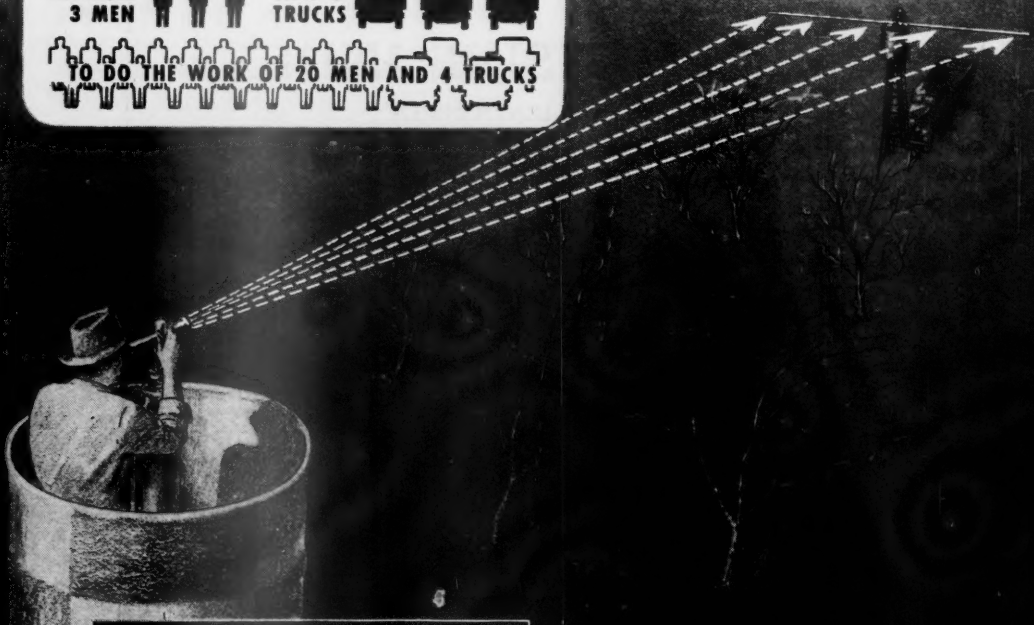

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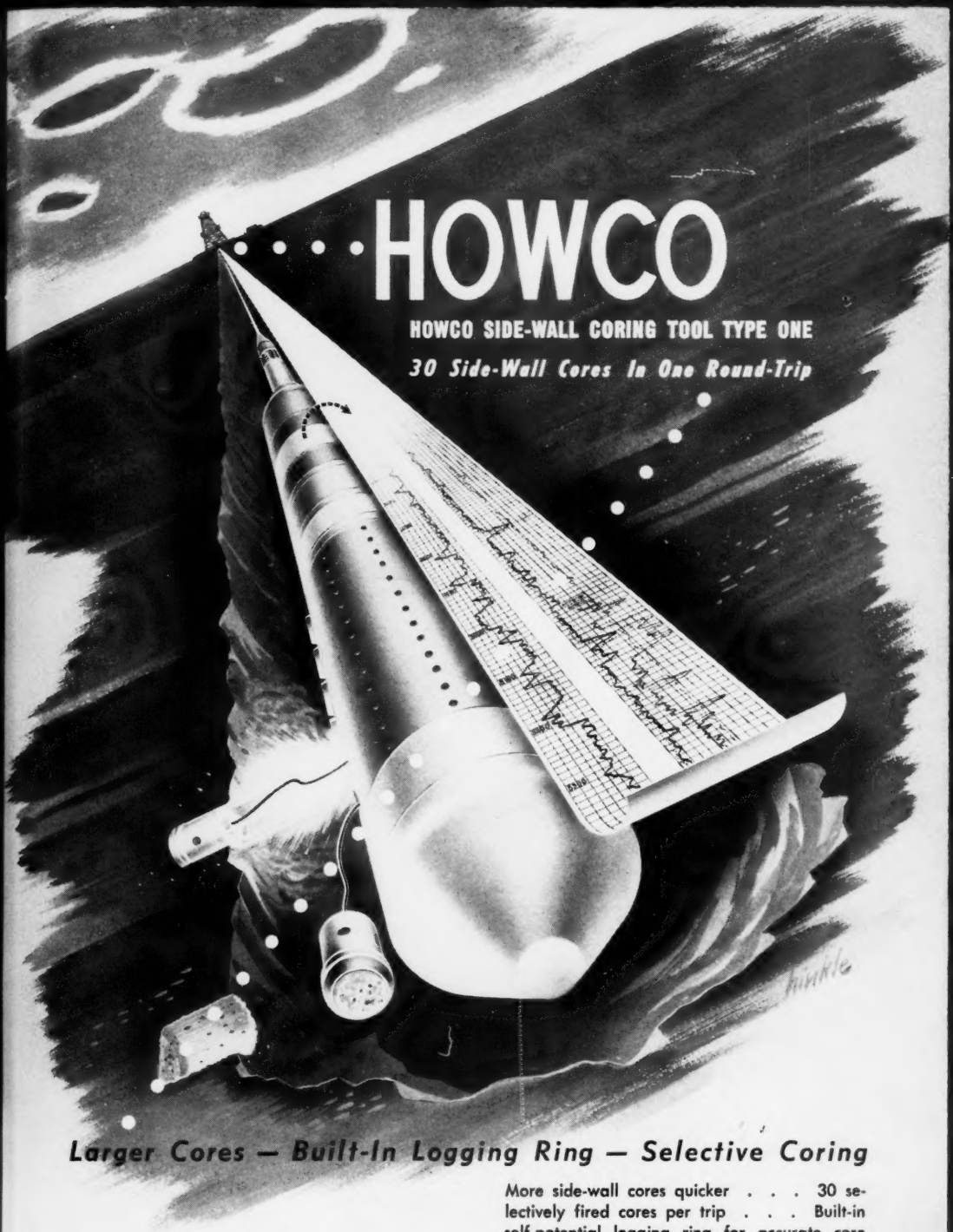

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